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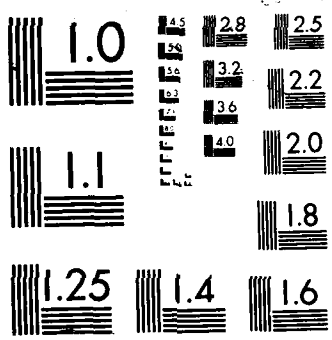

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THESIS

PRELIMINARY STUDIES OF A TECHNIQUE FOR MEASURING THE VOLUME BACKSCATTERING FROM SEDIMENTS

by

Federico René Diaz

SEPTEMBER 1986

Thesis Advisors: James V. Sanders
Alan B. Coppens

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

An experimental study was performed to devise a technique for measuring the volume backscattering from sediments. This experimental technique has never been performed in the laboratory. The volume backscattering was to be determined by comparing the echoes returned from the sediment with the echoes returned from the water/air interface. Measurements made on echoes returned from the water/air interface indicated that the apparatus, data acquisition system, and analysis system were performing correctly. Two types of sediments (fine sand and aggregate gravel) were used. The fine sand did not produce measureable volume backscattering and the aggregate showed results that depended on the region of sediment ensonified. It is recommended that a sediment more homogeneous than the aggregate, but with more backscattering than the fine sand be used in future studies.

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Preliminary Studies of a Technique for Measuring the Volume Backscattering from Sediments

by

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ABSTRACT

An experimental study was performed to devise a technique for measuring the volume backscattering from sediments. This experimental technique has never been performed in the laboratory. The volume backscattering was to be determined by comparing the echoes returned from the sediment with the echo returned from the water/air interface. Measurements made on echoes returned from the water/air interface indicated that the apparatus, data acquisition system, and analysis system were performing correctly. Two types of sediments (fine sand and aggregate gravel) were used. The fine sand did not produce measureable volume backscattering and the aggregate showed results that depended on the region of sediment ensonified. It is recommended that a sediment more homogeneous than the aggregate, but with more backscattering than the fine sand be used in future studies.

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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ACKNOWLEDGEMENTS

The author expresses his appreciation to the Office of the Director, Charting and Geodetic Services (NOAA), Lieutenant Commander David Gardner, Lieutenant Chin-Wen Chang (Republic of China), Mr. Greg Pless, Mr. Dale Galarowicz, and Mr. Chris Flanigan (University of California at Santa Cruz) for their support, advice and direction in this project.

I. INTRODUCTION

The basic problem of any echo-formation model designed to study the properties of the ocean bottom is to predict the shape of the echo from the ocean bottom. The important geometric quantities, beam angle θ, range R, bottom roughness η, and length scale L, are shown in Figure 1.1. Additional parameters are acoustic wavelength λ, wavenumber $k = 2\pi / \lambda$, and frequency $f = c / \lambda$, where c is the speed of sound in water.

A sound returning from a sedimentary bottom is subject to three types of reflection or scattering: 1) coherent reflection from the bottom, 2) incoherent scattering from the surface irregularities of the bottom, and 3) incoherent scattering from within the volume of the sediment due to the irregular matrix of the sediment. Physically, 3) is independent of 1) and 2) except for the reduction in acoustic amplitude caused by reflection at the surface; once the sound has penetrated the seawater/sediment interface, the existence of the interface has no effect on the transmitted sound wave (Clarke, Proni, Seem, Tsai, 1984).

The bottom echo model as presently formulated by Atlantic Oceanographic and Meteorological Laboratory (AOML), assumes a Raleigh scattering model for scattering of acoustic waves of wave number k from the individual grains within the sediment. For the model, the bottom is assumed to be composed of uniform sediment with grains of radius "a". Use of the Raleigh scattering approximation requires the grains to be very small compared to wavelength ($ka << 1$) as suggested in Figure 1.2.

Figure 1.3 shows the complicated nature of the acoustic cross section for backscattering for $ka \sim 1$ for spherical particles. It has been hypothesized that the ensemble averaged scattering from a collection of irregular shaped sediment particles has a simple form, but the difficulty of incorporating even a simple cross section function into a realistic theory of sediment scattering is formidable.

The direct measurement of the backscattering cross section of bulk sediments for a range of frequencies and grain sizes can be used as input to any echo formation model. The values of backscatter versus frequency can also be used to constrain and test theoretical models of acoustic backscattering from bulk sedimentary materials.

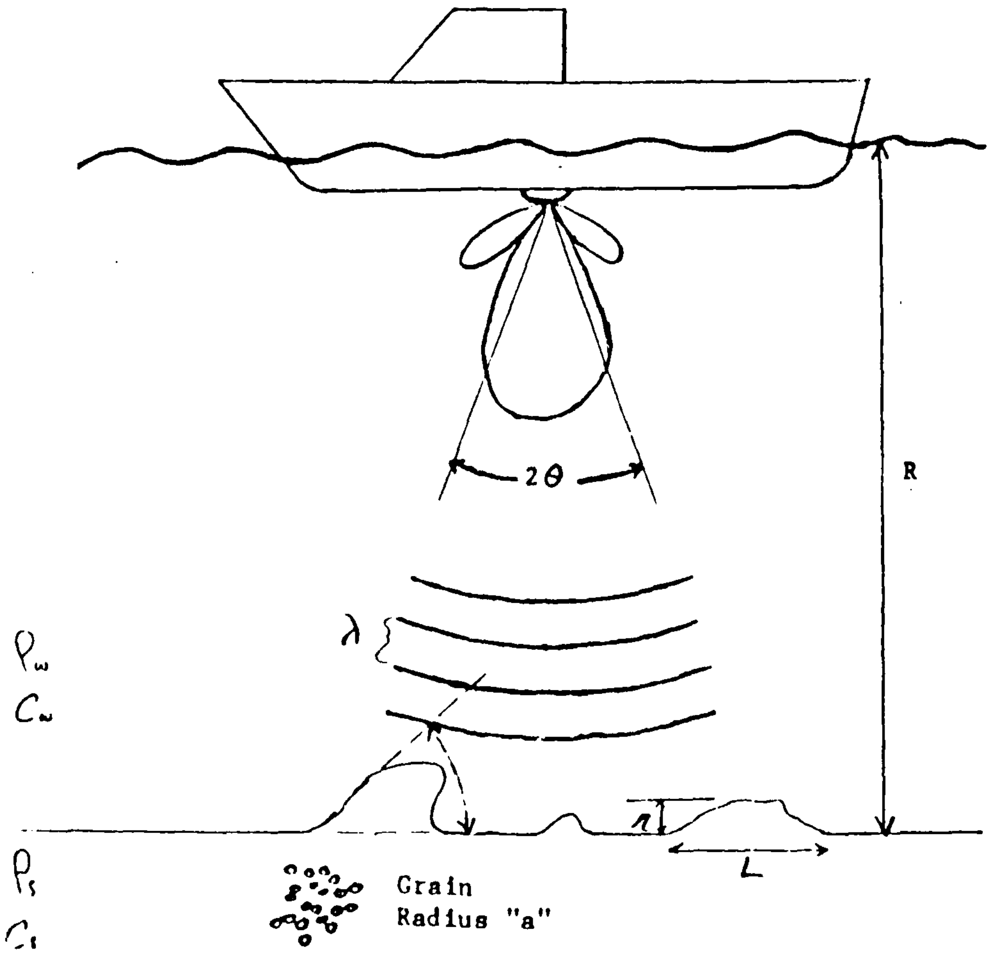

Figure 1.1 Basic Acoustic Quantities.

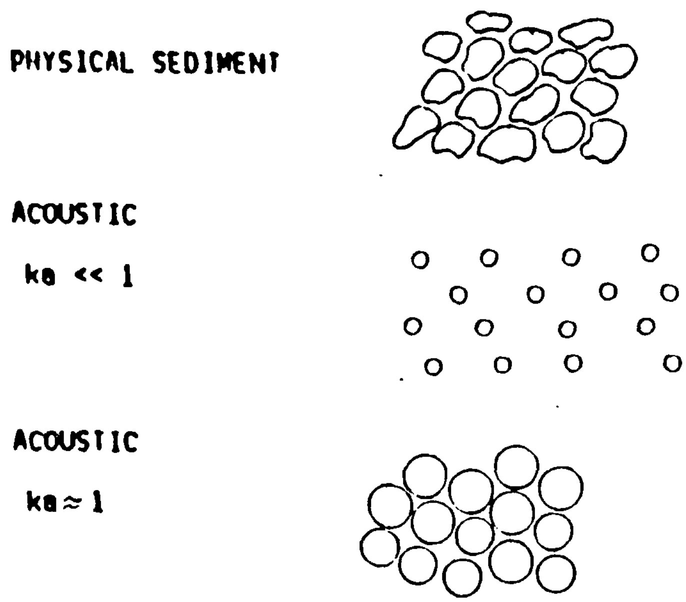

Figure 1.2 Grain Sizes.

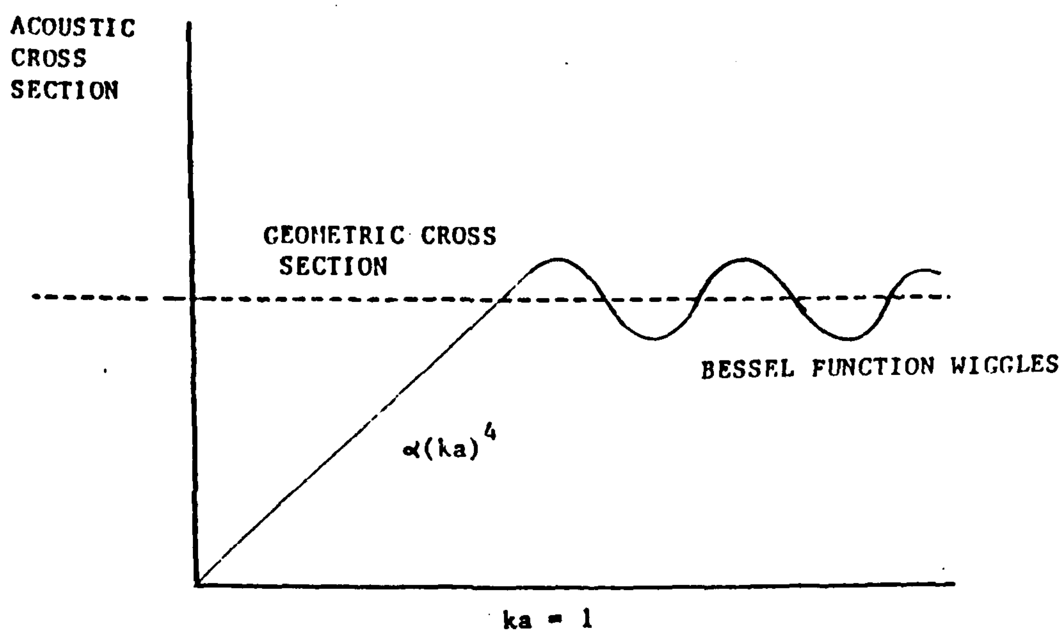

Figure 1.3 Cross Section in Region ka ~ 1.

II. BACKGROUND

In the Summer of 1984, a joint program for investigating the mechanism of the formation of acoustic bottom echoes was initiated by the Office of Charting and Geodetic Services (CGS), National Ocean Service (NOS) and by the Atlantic Oceanographic and Meteorological Laboratory (AOML) of the Environmental Research Laboratories (ERL) of the National Oceanic and Atmospheric Administration (NOAA). The objective of this research was to obtain a better understanding of the complex interaction of sound, including its transmission and reflection, with the diverse types of bottoms encountered in U.S. coastal waters.

A major tool of the CGS is the acoustic echo sounder which is used to obtain accurate bottom depth information for the construction of nautical charts. More recent technological innovations include the use of two-frequency, two beam-width echo sounders and multiple-beam bathymetric swath survey systems (BS^3 and Sea Beam) as well as enhanced digital recording systems. To understand the limitations and possibilities of these instruments, a good empirically tested model, or perhaps models, of the formation of echoes arising from bottom sound scattering or reflection is needed.

An additional benefit that could result from a theoretical and empirical understanding of the acoustic echo formation process would be the ability to classify sediment on the basis of the echo waveform. This ability would permit nautical charts to contain greatly expanded information about the bottom type. Exploration of the U.S. Exclusive Economic Zone (EEZ) would also be enhanced by a remote-classification ability.

III. EXPERIMENTAL DESIGN

A. MATERIAL SELECTED

Two materials, #30 Monterey fine sand for a fine grain sediment and Monterey Aquarium #2 for a rough gravel sediment, were used. To remove trapped air bubbles from the sediment, the sediment/water mixture was vigorously mixed by pumping a high-speed jet of bubble-free water into the mixture until no further bubbles could be seen rising from the agitated sediment. The sediment was then left in water for two to three days to allow any remaining air bubbles to dissolve. Bleach was added to the water to control biologic growth.

B. TEST TANKS

Initial experiments were conducted in a steel-bound glass tank, measuring 70 cm x 70 cm x 60 cm. This tank was filled with 50 cm of sediment below 20 cm of water.

A second tank, constructed of wood and measuring 3 m x 1 m x 1 m, was used to hold the #30 fine sand sediment. A sediment layer of 40 cm was used for the experiments The sediment surface was kept smooth and flat throughout the entire experiment.

A third facility consisting of a wooden tray, measuring 60 cm x 60 cm x 122 cm, was fabricated to hold about 90 cm of aggregate Aquarium #2. This tank was lowered and suspended 50 to 100 cm below the water surface of the NPS anechoic tank, Figure 3.1.

C. ELECTRONIC EQUIPMENT

A schematic drawing of the equipment configuration is shown in Figure 3.2. All components were off-the-shelf.

The output from a General Radio Model 1310 oscillator with a nominal frequency of 185 kHz was fed simultaneously into Hewlett-Packard 5233L frequency counter and a General Radio Type 396-A Tone Burst Generator to generate 16- or 32-cycle pulses. The output then passed through a Hewlett-Packard 467-A Power Amplifier set for unit amplification and a Datasonics Transmit/ Receive (T/R) switch, (Circuit Diagram, Figure 3.3). Before being fed to the transducer, the input signal was used to trigger a Nicholet Model 3091 Digital Oscilloscope.

The transducer, an F-41 circular-piston type with a 8.8 cm diameter active face and a thickness of 4.4 cm, was used as both transmitter and receiver. Its resonance frequency was 185 kHz. At this frequency, the 16-cycle pulse had a 13.3-cm pulse length in water, and the 32-cycle pulse twice that.

The received signal was amplified 20 dB by a Hewlett-Packard 465-A preamplifier, passed through a Spencer Kennedy Laboratories, Inc. Model 302 variable electronic filter (set at 136.0 kHz high pass) to eliminate low frequency noise, and then passed to the digital oscilloscope where the digital output was stored for later analysis.

Initially, ringing within the T/R switch caused problems. After consultation and investigation by technicians, it was concluded that there were problems with the diodes within the network of the T/R switch. Replacement of the diodes alleviated, but did not solve the problem. A high pass filter, placed externally to the T/R switch, was then fabricated by the electronics technicians of the Physics Department to suppress the 21 to 28 kHz transient that remained after replacement of the diodes. The circuit diagram for this high pass filter is shown in Figure 3.4.

D. MEASUREMENT OF THE PROPERTIES OF THE RECEIVED SIGNAL

The received signal displayed on the digital osciilloscope consisted of a 16- or 32-cycle, 185 kHz pulse modified by 1) the transmitting electronics (including the T/R switch), 2) the transmitting properties of the transducer, 3) the reflective properties of the sediment, 4) the receiving properties of the transducer, and 5) the receiving electronics. Since it was desired to measure the effects of the sediment on the pulse, the effects of the other mechanisms had to be determined by observing the received signal in the absence of any contribution from the sediment.

1. Effects of the transmitting electronics

The direct observation of the electrical signal applied to the transducer showed that (once the problems with the T/R switch were rectified) the signal was a clean square wave. This demonstrated that the transmitting electronics had negligible effect on the received signal.

2. Effects of the transducer

Since the transducer is a resonant system with damping, the square electrical pulse was transformed into an acoustic pulse with an exponential rise, a flattened top and an exponential decay.

To determine the waveform emitted by the transducer, the F-41 transducer was leveled and then clamped, with its active face pointing upward, to a vertical shaft, which was used to lower the transducer to a pre-determined depth below the surface in the anechoic tank (Figure 3.5). The signal received after reflection from the water/air interface should be an accurate representation of the signal emitted by the transducer. A typical envelope of this signal is shown in Figure 3.7, where a long tone burst was used to display the 32-cycle exponential rise and fall of the pulse envelope.

3. **Effects of the reflective properties of the sediment**

Reverberation within the sediment altered the exponential decay of the pulse.

For the purposes of sediment echo measurements, the F-41 was leveled and clamped to the vertical shaft to ensonify the sediment within a wooden tray suspended in the anechoic tank. The most accurate means of leveling the transducer was to laterally tilt the vertical shaft (with the F-41 attached) until the best possible waveform and largest amplitude were observed on the digital oscilloscope (Figure 3.6).

The transducer was moved horizontally (2 to 3 cm) between data sets to introduce variation in the propagation geometry and thereby provided a more varied ensemble for waveform averaging. The transducer was not moved after each sample, as requested by AOML, as it made data acquisition too time consuming.

4. **Effects of the receiving electronics**

An analog signal is characterized by continuous voltage variations. The Nicholet 3091 Digital oscilloscope converts the analog signal into discrete, digitized voltages and displays the resulting waveform as discrete points.

At a signal frequency of 185 kHz, a sampling rate of 1 μs gives only 5.4 samples per period, which is not fast enough to give an accurate display of the waveform (Figure 3.7). However, observations showed that there was natural "jitter" in the triggering of the scope so that for consecutive pulses, the scope would sample different parts of the waveform. To obtain an accurate representation of the received waveform, a large number of waveforms were sampled and the results stored. If sufficient "jitter" is present, the voltages stored in a given bin should vary between the maximum and minimum voltage in the waveform at the time corresponding to the bin. Squaring and averaging the voltages in each bin for a large number of samples should give an accurate representation of the waveform envelope.

The major goal of this experimental project was to determine the effects of reverberation in the sediment by accurately measuring the difference in the decay time

for the "tail" of the reflected pulse from the sediment and the reflected pulse from the water/air interface.

E. DIGITAL DATA ACQUISITION AND PROCESSING

Digital data were stored in the digital oscilloscope and then "dumped" to an HP-86 desktop computer. The digitized data were then squared and averaged over many pulses (i.e., 50 to 100 waveforms per set) and stored on disk. The averaging window was chosen to begin at the starting time of the exponential decay. The data were processed in two ways:

(1.) The natural logarithm of the averaged squared voltages in each bin was plotted versus time (Figure 3.8).

(2.) The natural logarithm of the averaged squared voltages of the local maxima were plotted versus time (Figure 3.9).

The following computer programs were written on HP software using an HP-86 desktop computer.

THIESE 1 = Data acquisition program
MAXI = Determination of local maxima
PLOT = Plots all averaged points as a function of time.
PLOT 1 = Plots local maxima as a function of time and determines slope of the line.

These programs are shown in Appendix A.

F. DIAGNOSTIC TESTING OF THE EXPERIMENTAL SYSTEM

1. The averaging program was verified by connecting a simple RLC series circuit in place of the transducer and T/R switch to produce a waveform similar to that produced by the F-41 transducer, but at 5 kHz. Using the data acquisition equipment, the data were squared and averaged over several pulses and the results were compared to the voltage readings manually recorded using the built-in curser on the 3091. The comparison was excellent.

2. The echo received from the water/air surface were observed on the Nicholet 3091 to determine if sufficient natural "jitter" exits to allow accurate measurements of the 185 kHz signal. Five data sets with an increasing number of waveforms were stored.

Set 1 - 5 waveforms
Set 2 - 10 waveforms
Set 3 - 25 wavefroms
Set 4 - 50 waveforms
Set 5 - 100 waveforms

The voltages for each set were squared and averaged. The logarithm (LN) of each average was plotted as a function of time (bin number). When the number of waveforms used were not sufficient, the scatter on this plot was significant. If enough waveforms are used the scatter on the plot should decrease until the scatter becomes constant with the increasing number of waveforms. The results of this test showed that 50 waveforms were the maximum number required for each data set.

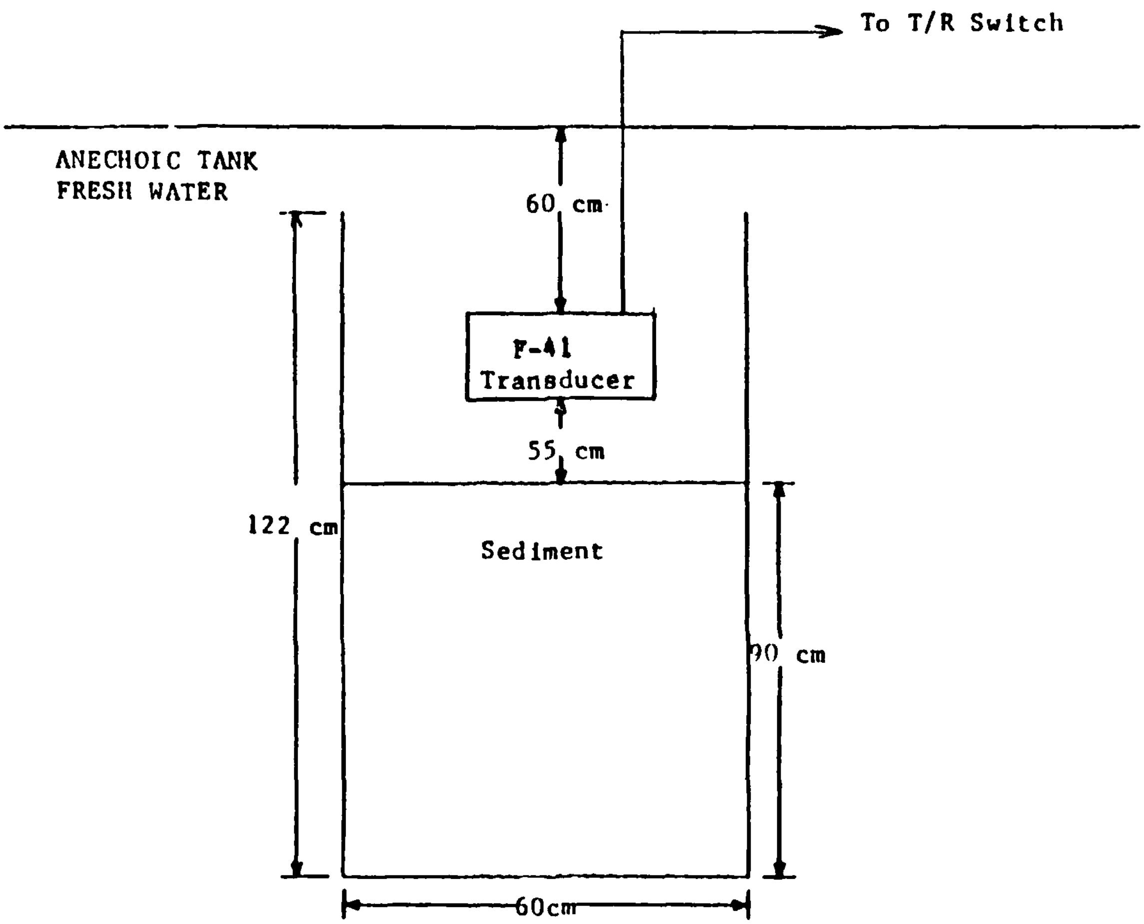

Figure 3.1 Experimental Tray Setup.

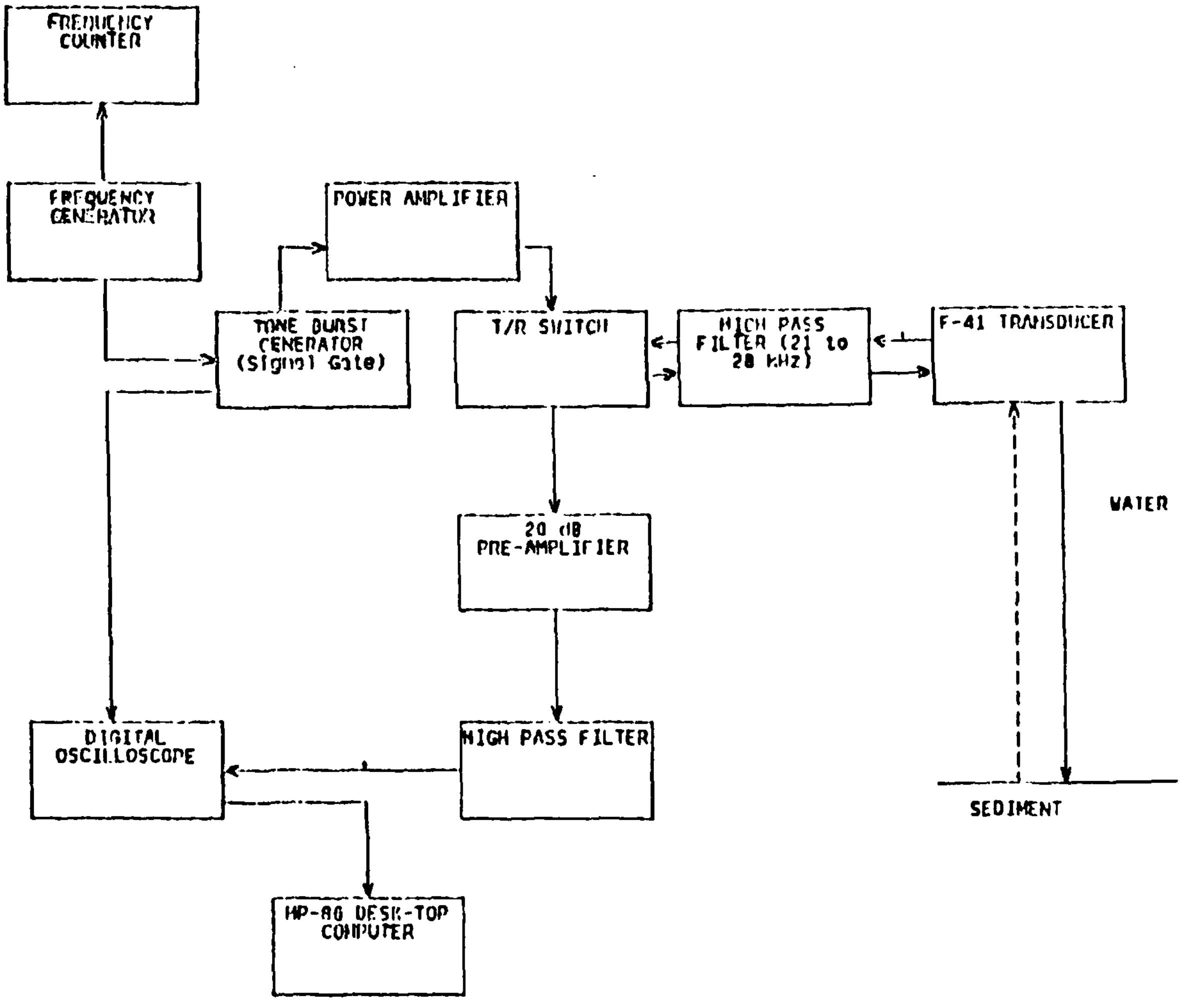

Figure 3.2 Electronic Equipment Schematic.

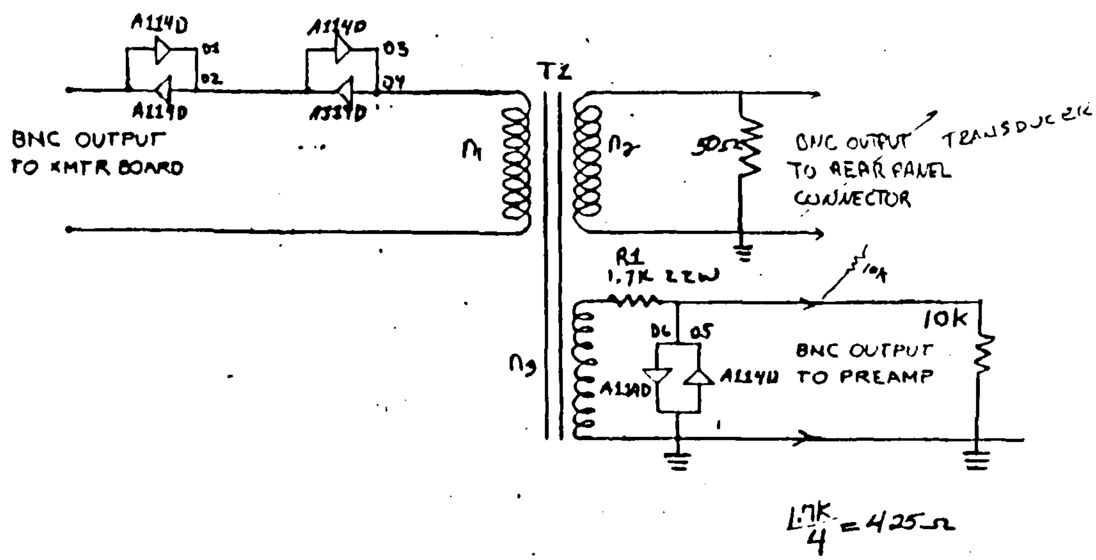

Figure 3.3 T/R Switch Circuit Schematic.

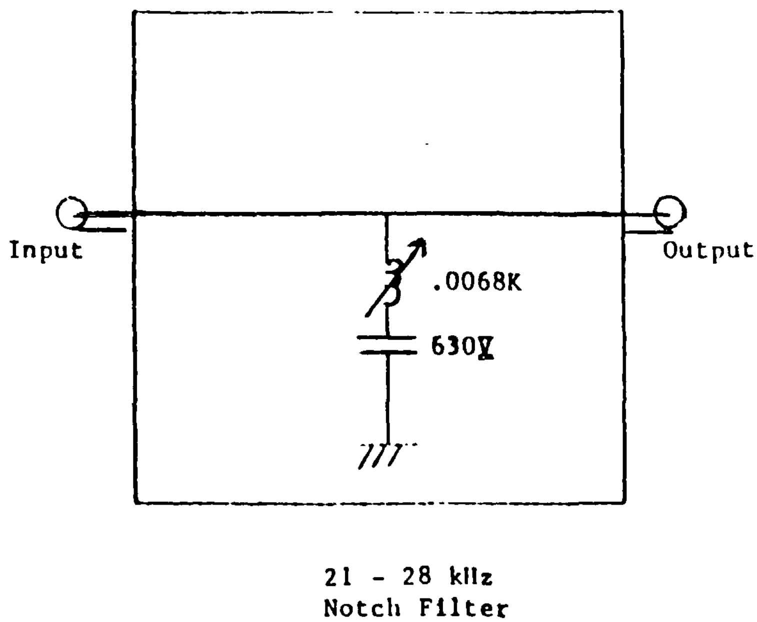

Figure 3.4 High Pass Filter Schematic.

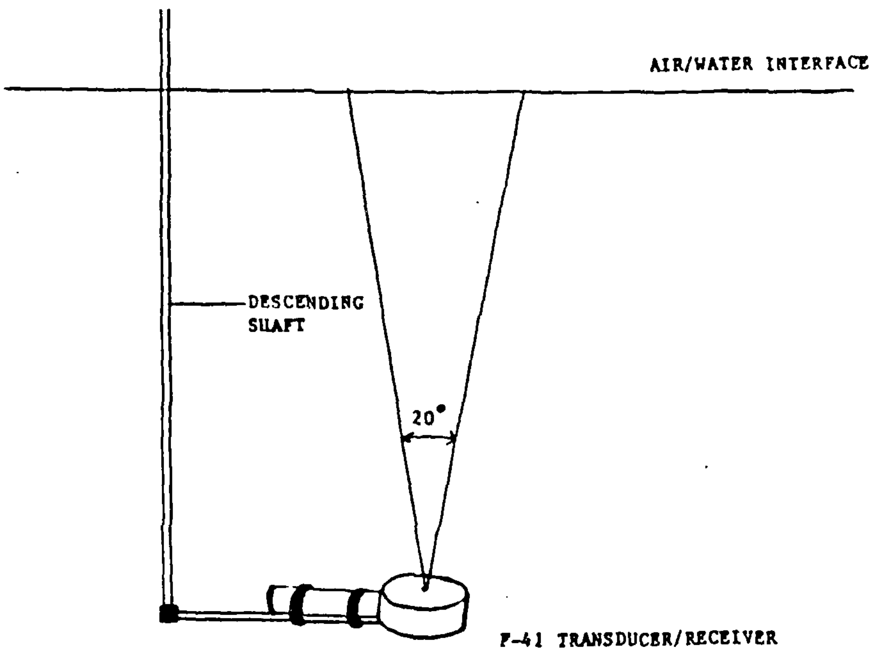

Figure 3.5 Water Reflection Arrangement.

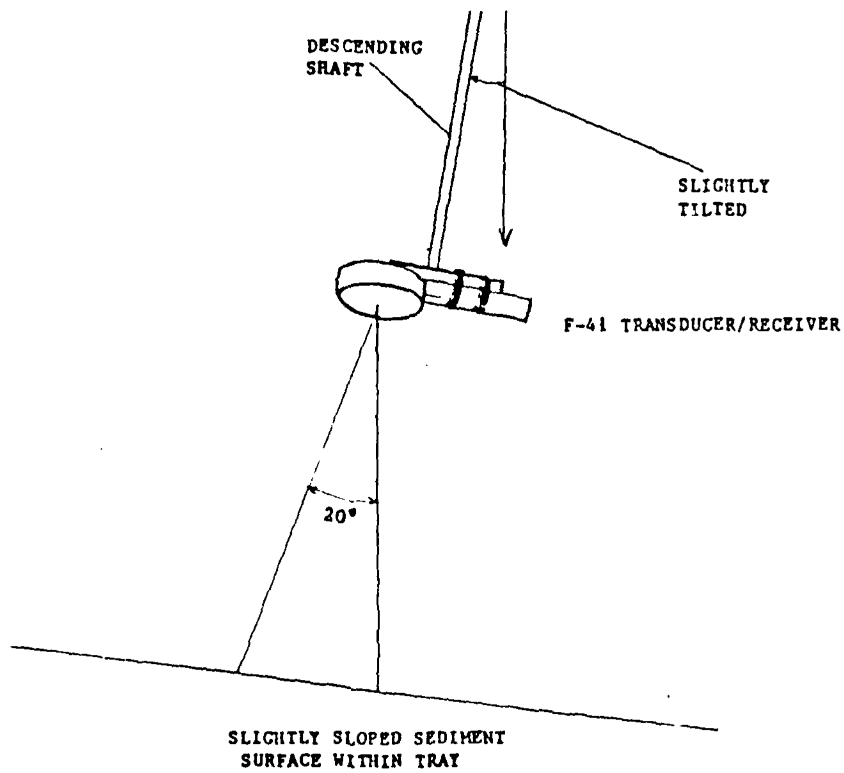

Figure 3.6 Sediment Reflection Arrangement.

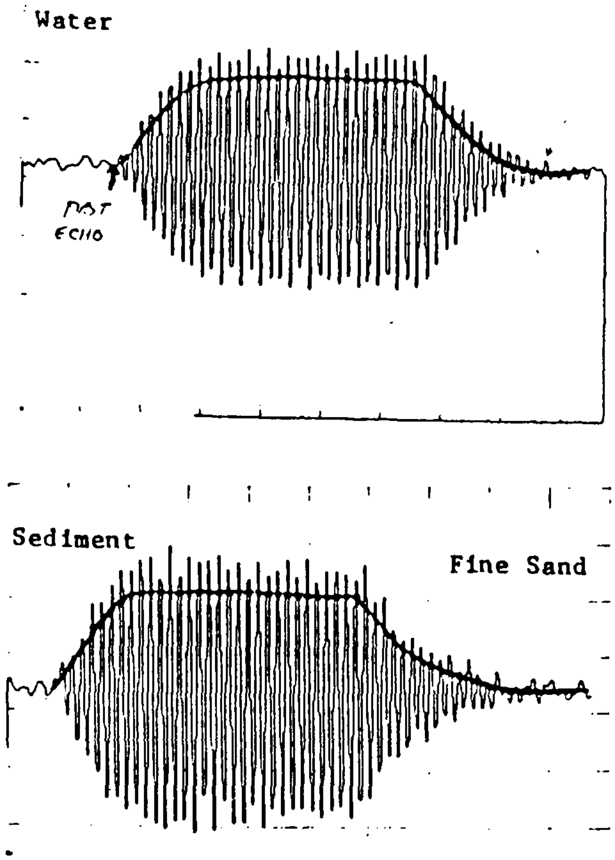

Figure 3.7 Water and Sediment Echo Envelopes.

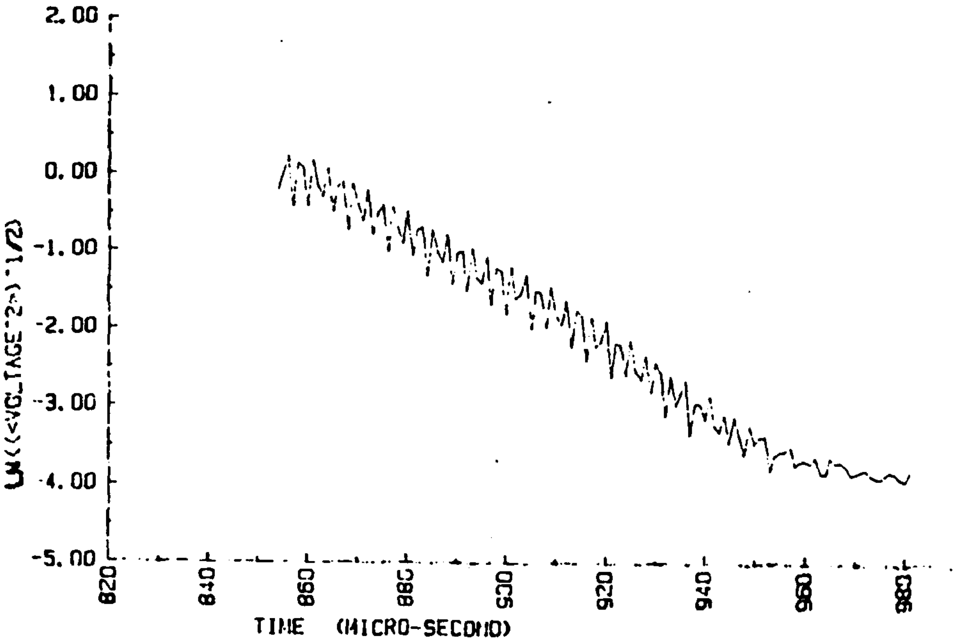

Figure 3.8 Averaged Squared Voltages in a Bin (Tail Portion).

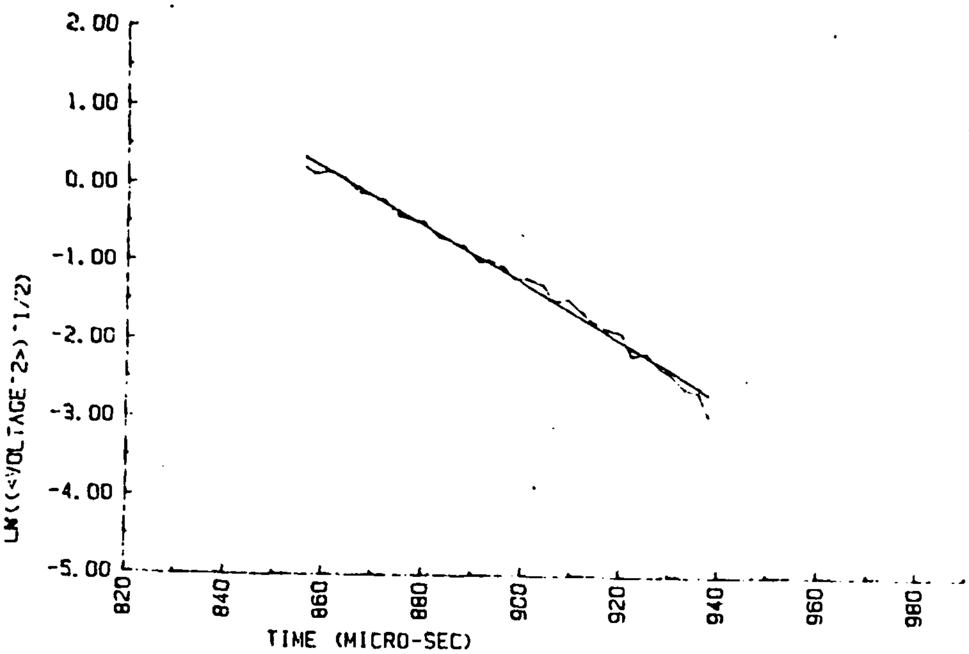

Figure 3.9 Averaged Squared Voltages of the Local Maxima.

IV. PRELIMINARY MEASUREMENTS

A. WATER

The expected density of room temperature water is 1.00 g/cm^3 (Lange, 1967). Measured volumes of the water, taken from the tanks, were periodically weighed and the observed density was 1.00 $\pm$ 0.01 g/cm^3 .

Speed of sound experiments for fresh water were performed as a check on the equipment and experimental techniques. LC10 hydrophones were used in these measurements both as transmitter and receivers. The LC10 is a small (0.97 cm diameter) cylinder with a receiving range of 0.1 to 120,000 Hz. The LC10 was designed to be omni-directional in a plane perpendicular to the axis of the cylinder with a tolerance of $\pm$ 1 dB at 100 kHz. A directivity pattern for an LC10 (measured at 180 kHz) is shown on Figure 4.1.

This experiment involved the use of three LC10 hydrophones (Figure 4.2). One was used as the source. A second LC10 was placed 10 cm from the source and the third LC10 was moved along a line passing through the other two transducers. The travel time between the receivers was measured, and the data are summarized in Table 3 of Appendix B. A plot of distance versus time is in Figure 4.3.

The measured sound speed of water was 1453 $\pm$ 20 m/s. As a check, the following equation (Kinsler, Frey, Coppens , Sanders, 1982) was used to calculate speed of sound for fresh water:

$$c = 1402.7 + 488t - 482t^2 + 135t^3$$

where $t = T/100$ and T is temperature in degrees Celsius. The measured temperature for the water was 16°C. The computed sound speed in water was 1467.90 m/s with an uncertainty of $\pm$ 0.01 m/s.

B. SEDIMENTS

1. Physical properties

Two types of sediment were sieved and sized by personnel of the Geology Department, University of California at Santa Cruz.

Monterey #30 Fine Sand = 300.0 μm

Aquarium #2 Aggregate = 5.3 mm

Bradshaw (1981) measured the water-saturated density ρ_{mix} and dry density ρ_1 of the fine sand,

$$\rho_{mix} = 1.98 \pm 0.03 \text{ g/cm}^3$$
$$\rho_{dry} = 2.69 \pm 0.01 \text{ g/cm}^3$$

Density and porosity measurements were performed in the laboratory for the aggregate. Ten separate measurements, yielded a density of 1.97 $\pm$ 0.03 g/cm^3 for the water saturated sediment and a dry density ρ_1 of 2.64 $\pm$ 0.05 g/cm^3. The porosity β of the aggregate was measured to be 0.59 $\pm$ 0.01. The dry density was 2.64 g/cm^3 as computed from the following equation (Urick, 1979):

$$\rho_{mix} = \beta\rho_1 + (1 - \beta)\rho_2$$
$$\rho_{mix} = 1.97 \text{ g/cm}^3$$
$$\beta = \text{Porosity} = 0.59$$
$$\rho_1 = \text{Density of individual grains} = 2.64 \text{ g/cm}^3$$
$$\rho_2 = \text{Density of Water} = 1.00 \text{ g/cm}^3$$

The data are summarized in Table 2 of Appendix C.

2. **Sound speed**

Speed of sound for the sediment (aggregate) was performed as for water, except the transducer and two receivers were buried 10 cm below the surface of the sediment (Figure 4.4). The data are summarized in Table 4 of Appendix B. A plot of distance versus time is shown in Figure 4.5. The sound speed was linearly estimated (Figure 4.5) to be 1555 $\pm$ 50 m/s and measured to be 1583 $\pm$ 84 m/s. Comparison between measured and estimated values is good.

C. TESTS PERFORMED ON TRANSDUCER

1. **Beam pattern and beamwidth**

(a.) In the far field, the radiation from a continuous-line source can be expressed as a product of an on-axis pressure P_{ax} (r) which depends only on r and a term $H(\theta, \varphi)$, which depends only on angle. The term that depends on the angle, called the directional factor, is normalized so that its maximum value is unity (Kinsler, Frey, Coppens, Sanders, 1982). The directions for which $H = 1$ determine the acoustical axes. In cases with high degrees of symmentry, the acoustic axis becomes a plane or a line. The variation of intensity level with angle is the beam pattern:

$$b(\theta, \varphi) = 10 \text{ LOG } \{I (r, \theta, \varphi) / I_{ax} (r)\}$$
$$= 20 \text{ LOG } H(\theta, \varphi)$$
$$= 20 \text{ LOG } \{P(r, \theta, \varphi) / P_{ax} (r)\}$$

Since the pressure amplitude (P) is proportional to the voltage amplitude (V):

$$20 \text{ LOG } \{P(r, \theta, \varphi) / P_{ax}(r)\}$$
$$= 20 \text{ LOG } \{V(r, \theta, \varphi) / V_{ax}(r)\}$$

The term $P_{ax}(r)$ is the far-field pressure on the acoustic axis; the pressure along any other radial line is simply $P_{ax}(r)$ reduced by the factor $H(\theta, \varphi)$.

The beam pattern measured for the F-41, is shown in Figure 4.6. Data were recorded in increments of 5°. These data are summarized in Table 1 of Appendix B.

(b.) No standard value of the ratio $I(\theta, \varphi) / I_{ax}$ has been agreed on for measuring or calculating the angles θ and φ that mark the effective extremity of the major lobe. The particular value employed must be clearly stated when beamwidths are specified in this manner. The ratio used for this experiment was 0.5 (down 3 dB), so that:

$$-3 \text{ dB} = 20 \{\text{LOG } P(r, \theta, \varphi) / P_{ax}\}$$
$$-3 \text{ dB} = 20 \{\text{LOG } P(r, \theta, \varphi) / P_{ax}\}$$
$$P / P_{ax} = 0.7079$$

The beamwidth of a baffled circular piston source can be calculated from (8.36) and Table A6 of Kinsler, Frey, Coppens, and Sanders (1982) using

$$1.7 = ka \text{ Sin } (\theta)$$
$$\lambda = 0.83 \text{ cm}$$
$a = 4.4$ cm (radius of the active face of the F-41) we have
$$\theta = 3.00^{\circ}$$

The half beamwidth for the F-41 was measured to be 10°. The difference between the measured and calculated beamwidth is probably because the F-41 is not a baffled transducer.

2. **Near field**

In the near field of a transmitter, the sound field is irregular and does not fall off smoothly with distance, as in the far field. The two regions are separated by a transition region. In the near field the wavefronts are nondivergent; in the far field the wavefronts are smooth and spherical (Urick, 1983).

Axial voltage for a baffled circular piston source exhibits interference effects in the near field. The extremes of voltage occur for values of r satisfying:

$$(1/2)(kr)\{\sqrt{(1+(a/r)^2)} - 1\} = m\pi / 2$$

maxima: m odd
minima: m even

where m = 0,1,2,3,.... Solution of the above for values of r at the extremes yields

$$r_m / a = (1/m)(a/\lambda) - (m/4)(\lambda / a)$$
$$a = 4.4 \text{ cm}$$
$$\lambda = 0.833 \text{ cm}$$

The computed values of r at the extremes are

r_1 = 23.03 cm (maximum)
r_2 = 11.20 cm (minimum)
r_3 = 7.12 cm (maximum)

For values of r less than r_1, the axial voltage displays interference effects suggesting the complexity of the acoustic field near the face of the source. The distance r_1 serves as a convenient demarcation between the near field (near the source) and the far field (at far distances from the source).

Measurements were taken to determine the extent of the near field of the F-41. The F-41 was held fixed at one end of the tank, while a LC10 receiver was moved along the acoustic axis in uniform increments. The voltage readings were plotted as a function of inverse distance from 15 cm to 150 cm (Figure 4.7). In the far field the voltages display a decreasing behavior going asymptotically to a 1/r dependence. All reflection measurements were performed in the far field. A summary of these data are in Table 2 of Appendix B.

3. Pressure reflection coefficient

The pressure reflection coefficient at normal incidence were measured for both sediments and the results compared to those calculated from measured values of ρ and c. The reflection coefficient (R) is given by:

$$R = (\rho_W c_W - \rho_S c_S)/(\rho_W c_W + \rho_S c_S)$$

where

ρ_W = Density of Water

c_W = Sound Speed in Water

ρ_S = Density of Sediment

c_S = Sound Speed in Sediment

Model geometry for these experiments is shown in Figure 4.8.

The reflection coefficient for the fine sand was measured in the larger wooden tank. The sediment was kept smooth and horizontal for normal incidence. The F-41 was mounted at the surface of the water pointed vertically downward toward the sediment. The oscilloscope voltage V_2 readings of the received signal were recorded. The F-41 was then placed on the sediment bottom, pointed toward the water surface. The voltage reading V_1 of the received signal was recorded. The ratio of V_2 / V_1 is the *reflection coefficient. The experiments were performed at three different water depths* (40 cm, 35 cm, 30 cm) to ensure consistant observed values for R and to compare observed and computed values. A summary of the measured data is shown in Table 1 of Appendix C.

The density of the fine sand is 1.98 $\pm$ 0.03 g/cm^3 and sound speed is 1600 m/s (Bradshaw, 1981), giving a reflection coefficient for normal incidence of 0.36 (Borchardt, 1985). Measured reflection coefficient is 0.36 $\pm$ 0.01. Expected and measured reflection coefficients are in excellent agreement.

Reflection coefficient experiments on the aggregate were conducted in the steel-bound glass tanks. The aggregate was kept smooth and horizontal throughout the experiments. The values used in calculating the reflection coefficient for normal incidence for the aggregate were

ρ_W = 1.000 g/cm^3 ρ_S = 1.97 g/cm^3

c_W = 1452.95 m/s c_S = 1550.00 m/s

from which R = 0.356

These experiments were performed at three different depths (35 cm, 30 cm, 25 cm) to ensure consistancy of the experimental procedure. A summary of these results is shown in Table 1 of Appendix C.

The measured reflection coefficient for the aggregate is 0.26 $\pm$ 0.01. The computed and measured values for reflection coefficient are not in good agreement. In this case the Raleigh model (two fluid) does not apply (Anderson and Liebermann, 1968).

D. SUMMARY OF PRELIMINARY MEASUREMENTS

1. Test tank criteria

Trial runs in the wooden tank and in the glass-bound tank, showed that a longer pulse length would be required to ensure the signal emitted by the transducer reaches equilibrium and that the transmitted signal would not interfere with the receive signal. The wooden tray arrangement suspended in the anechoic tank provided the necessary water depth and sediment thickness required by the longer pulse.

2. Sediment criteria

It was decided not to use the fine sand as the echo showed minimal traces of volume backscatter. The aggregate was believed to have greater volume backscatter.

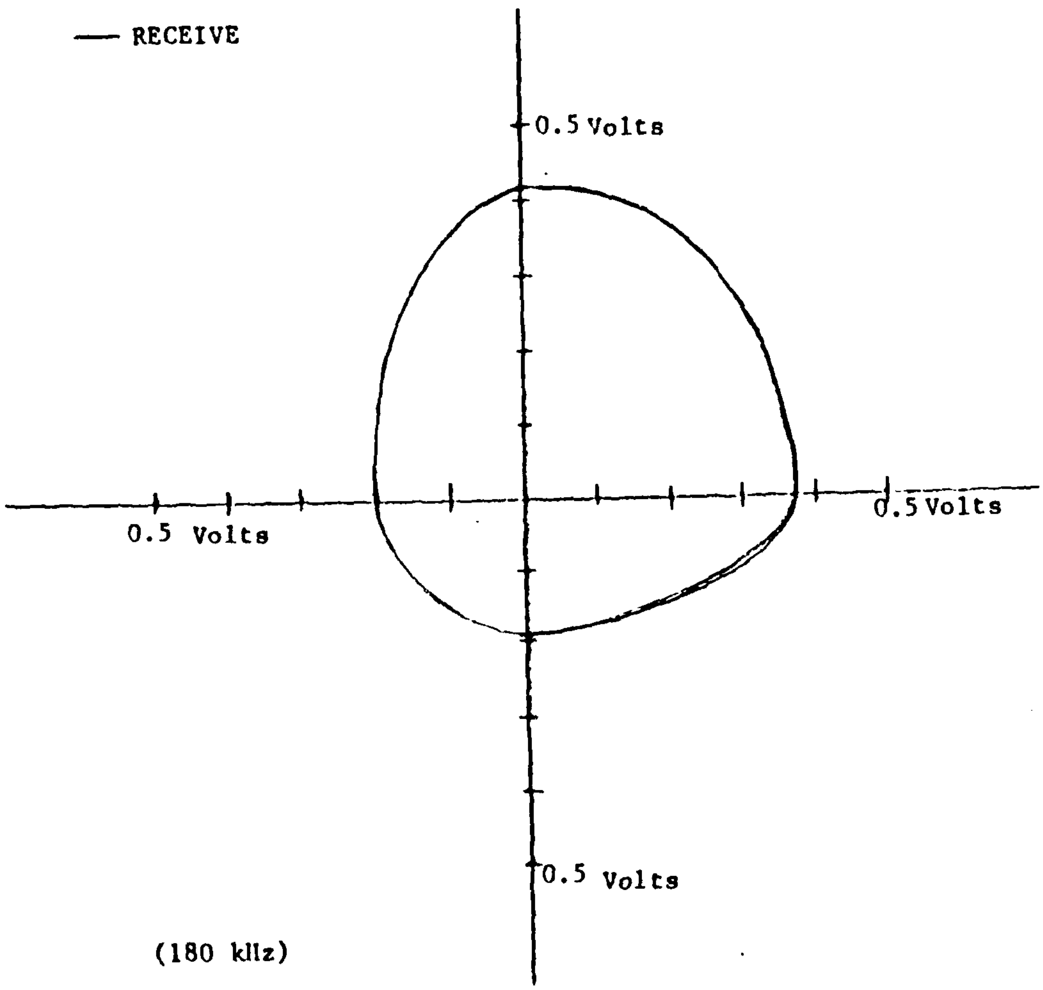

Figure 4.1 Directivity Pattern for A503 LC10 Receiver.

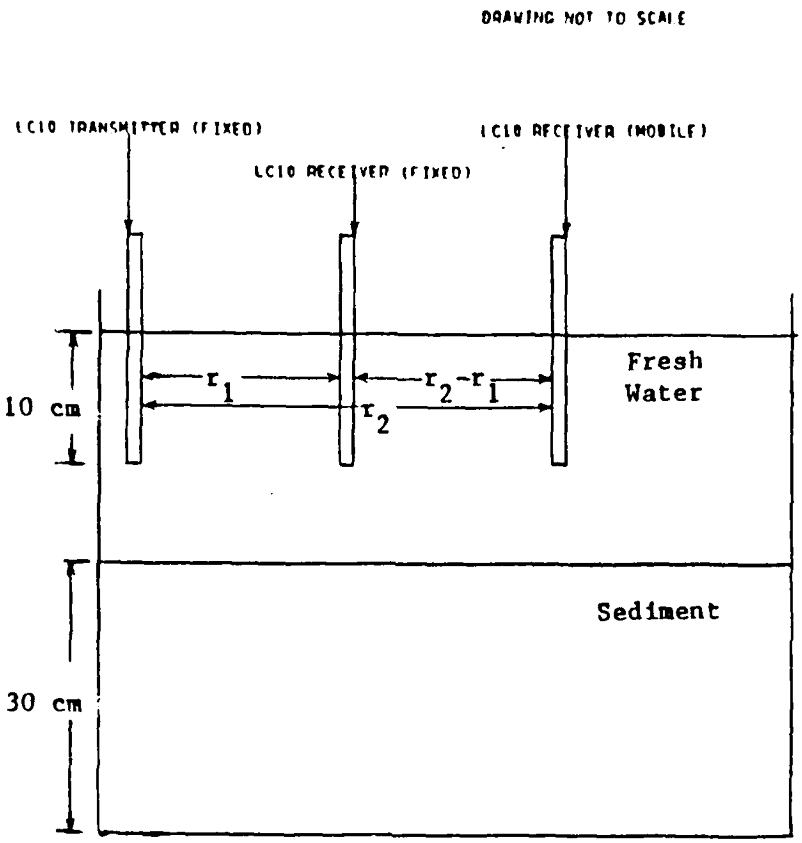

Figure 4.2 Model Geometry for Speed of Sound in Water.

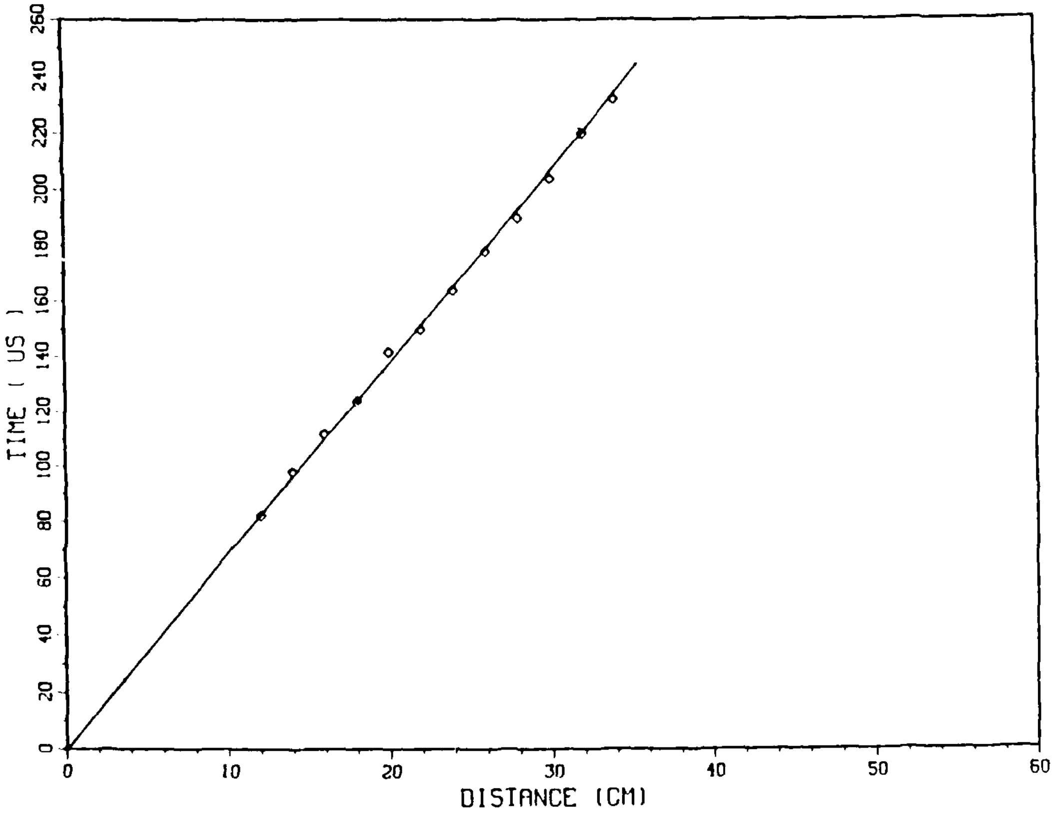

Figure 4.3 Distance versus Time (Water).

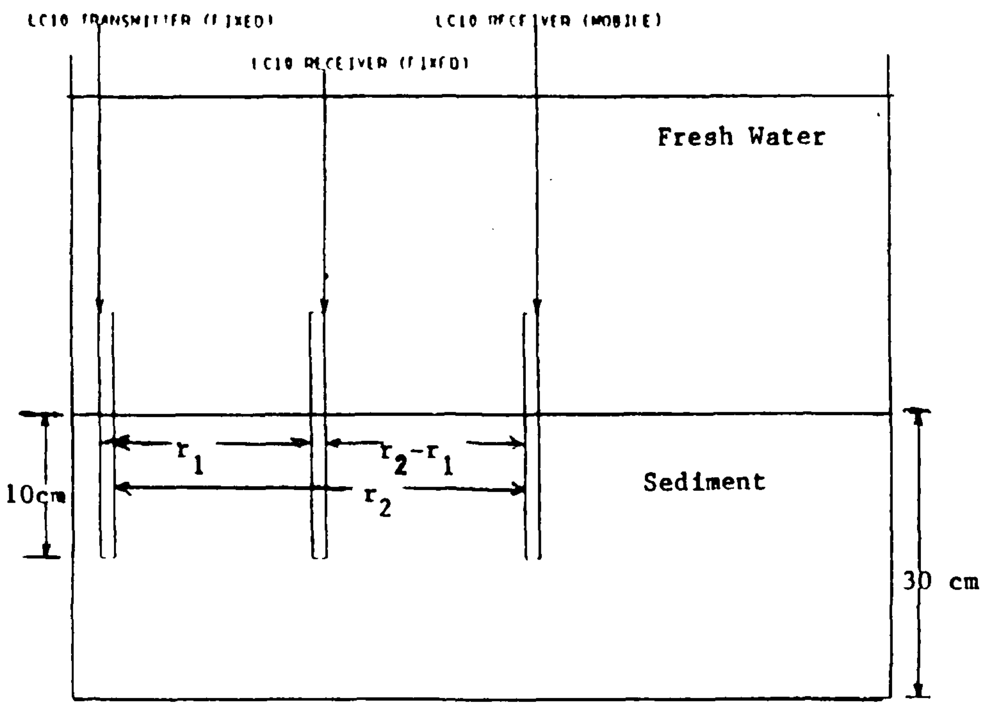

Figure 4.4 Model Geometry for Speed of Sound in Aggregate.

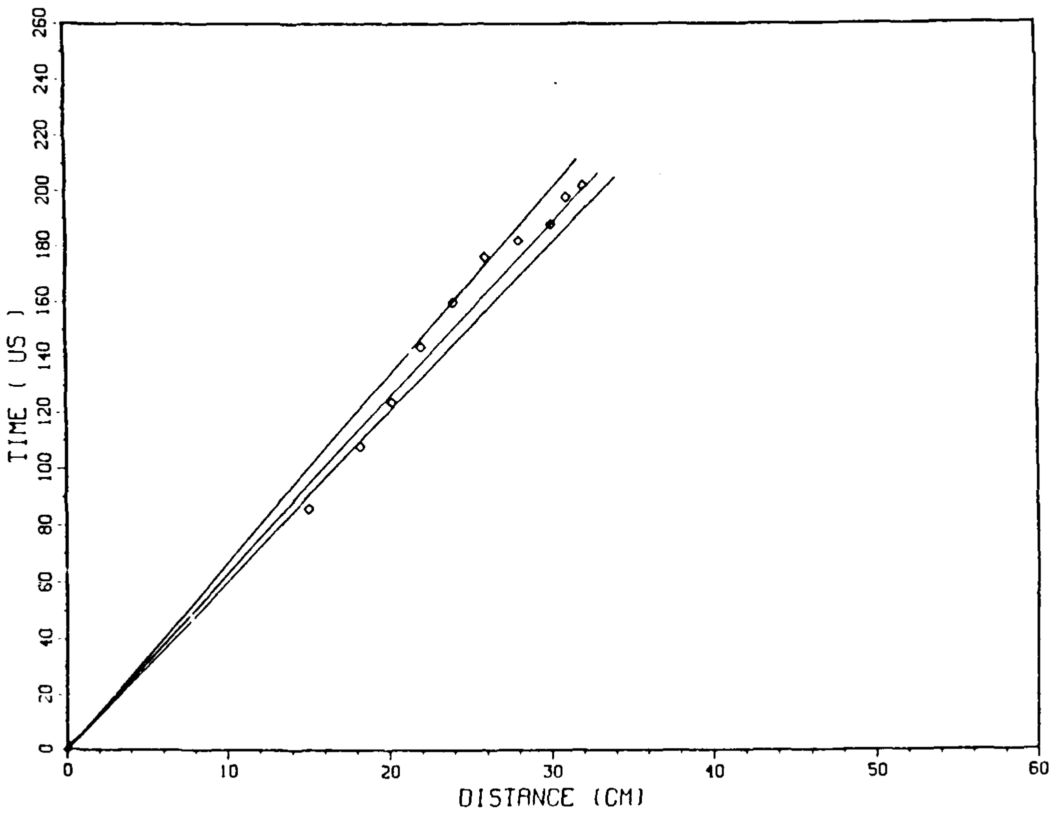

Figure 4.5 Distance versus Time (Aggregate).

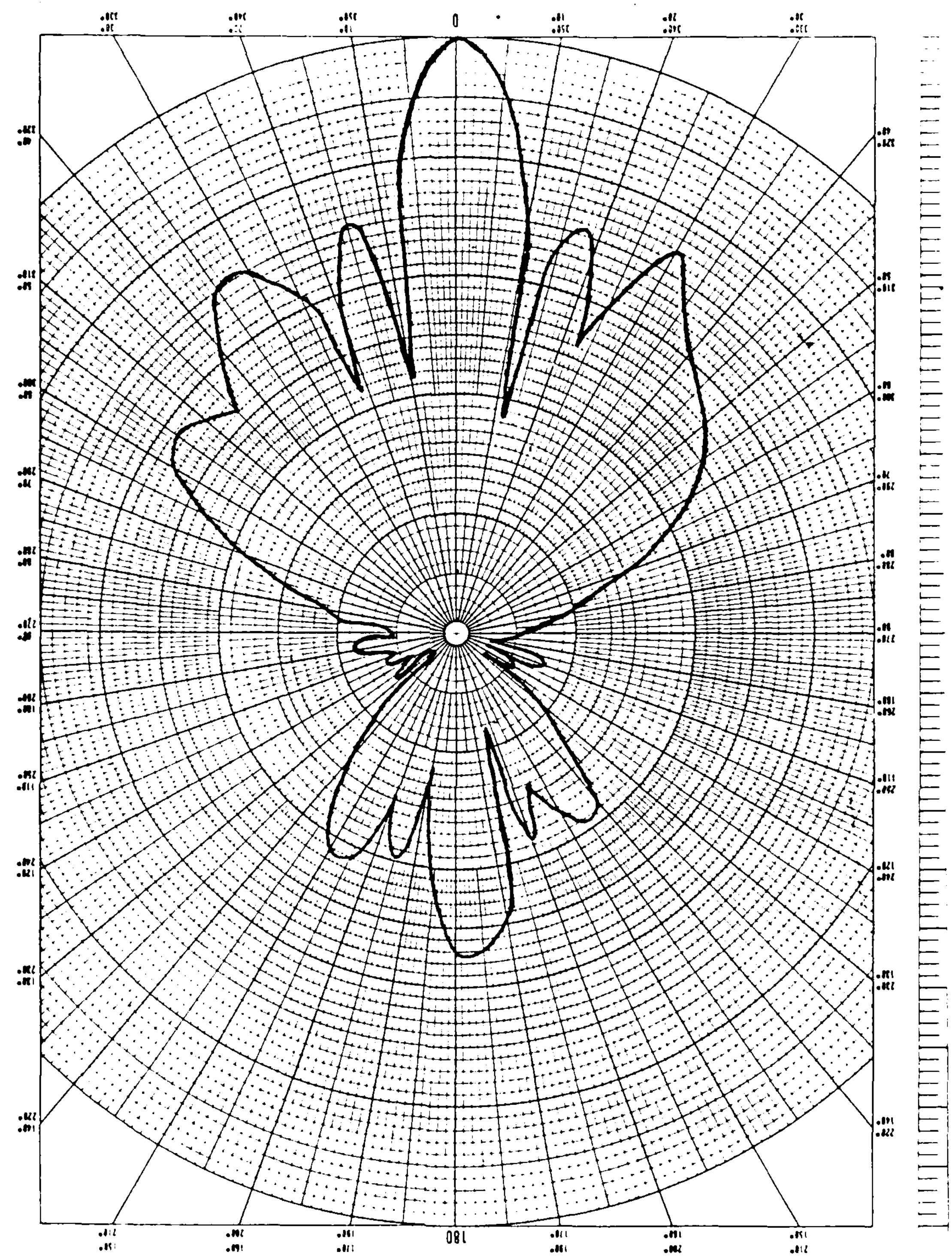

Figure 4.6 Beam Pattern for F-41 Transducer
(Units in dB).

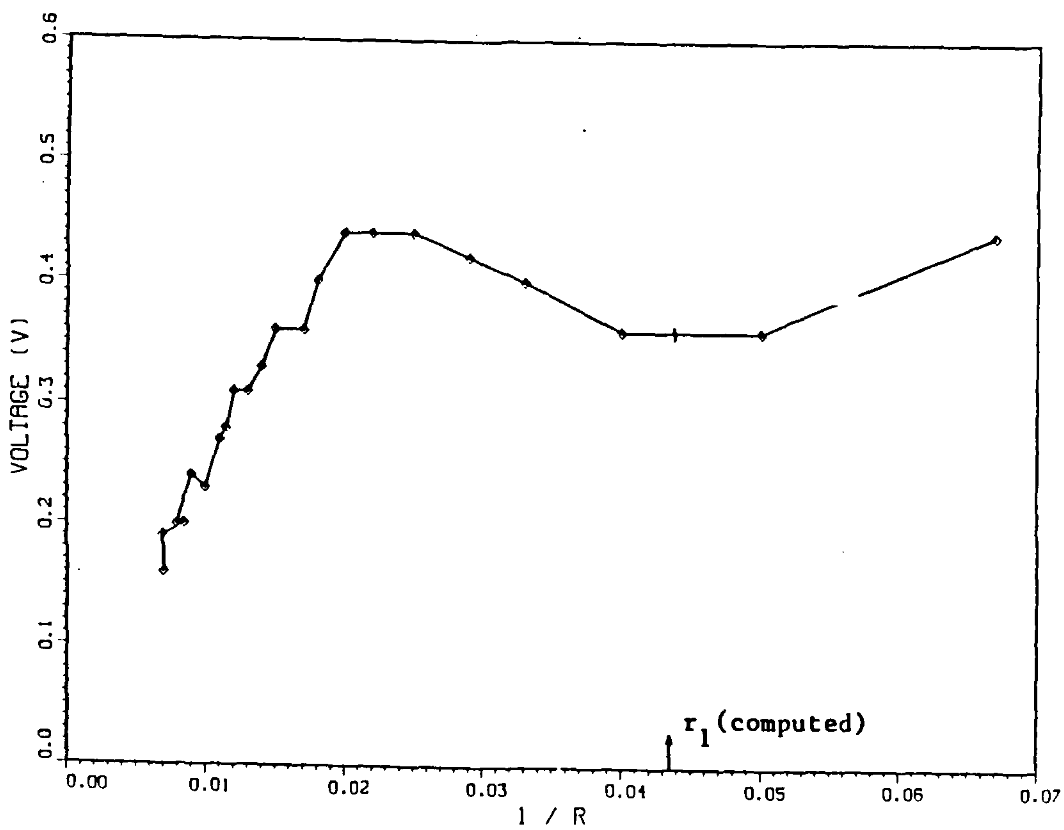

Figure 4.7 Extent of the Near Field.

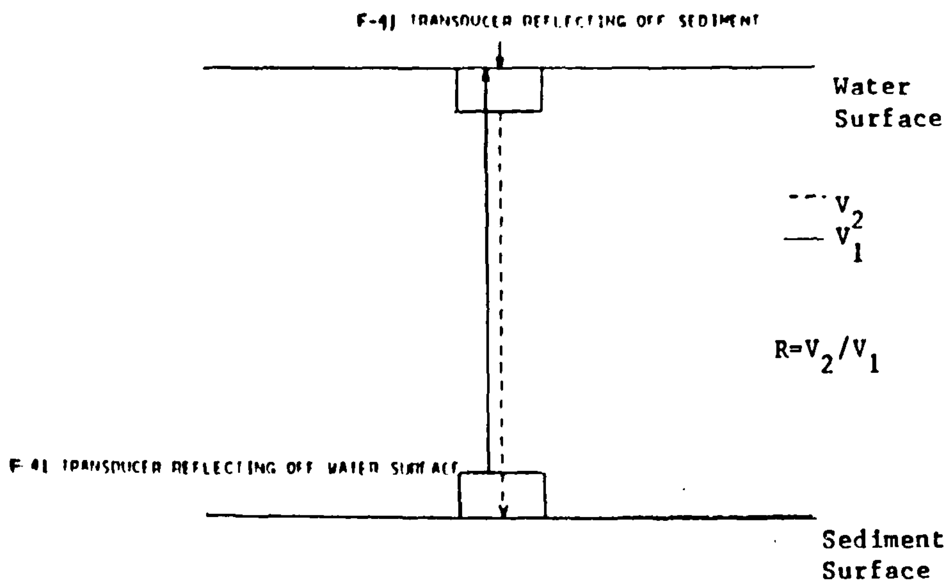

Figure 4.8 Model Geometry for Pressure Reflection Coefficient.

V. RESULTS

The data sets for reflection from the water/air interface are DATA3, DATA4 and DATA6 through DATA11, Appendix D. The distance between the F-41 and the water/air interface was kept constant at 55 cm for each set. These echoes were sampled from 840 μs to 983 μs after the beginning of the echo, and the sets are consistant up to 940 μ s. Interference, of an unknown source, began to occur at 940 μs. The data, truncated at 940 μs, shows a linear exponential decay. See Table 1, Appendix D for results. The mean value for the decay constant for the water/air reflection data is $(-3.84 \pm 0.14) \times 10^{-2}\ \mu s^{-1}$.

The data sets for reflection from the aggregate are DATA1, DATA2, DATA5, DATA12, DATA13 and DATA14, Appendix D. The distance between the F-41 and sediment was 55 cm, the same as for water. These echoes were sampled at the same time interval as for the echoes from the water/air interface. The unknown interference was again evident after 940 μs and the data were truncated at 940 μs.

There was considerable evidence of inhomogenities in the sediment. For a few locations, the decay was regular and exponential in nature, although with a decay constant different from that for the water/air interface.

For the sets DATA15, DATA16 and DATA17, the F-41 was set at 30 cm, 50 cm and 70 cm, respectively, above the sediment surface. The F-41 was moved horizontally to ensonify different areas of the sediment. For these selected samples, the mean value for the decay constant was $(-3.08 \pm 0.69) \times 10^{-2}\ \mu s^{-1}$. See Table 2 Appendix D for results.

The following general observation can be made:

> Slight variations in source positioning (vertically and horizontally) led to vastly different results.

VI. CONCLUSIONS AND RECOMMENDATIONS

At this point, measurement of volume reverberation within sediments is not predictable because of the inconsistancies of the data available. The study of the effects of source position on the results for reflection from the water/air interface did not uncover any major failures. In general, there was excellent consistancy among the measurements made on the water/air interface. Minor variations of source positioning had a pronounced effect on the echo reflection from the sediment.

Future experimentation should include further variation of the position of the source (horizontal and vertical) for water measurements to determine whether the experimental system operates consistantly before performing any additional measurements on sediment. It is recommended to use finer sediments or glass beads of uniform radius to test the importance of inhomogenities in the sediment. Further, it is recommended that the following equipment modifications be made:

(a) The carriage for holding the transducer should be re-designed to allow precise horizontal and vertical movement of the transducer. These movements should be recorded so that data sets could be duplicated if needed.

(b) Fabricate a smaller tray (e.g., 80 cm x 80 cm x 60 cm) using a sediment depth of 30 to 40 cm.

Continued use of the computer programs written for this project on the HP-86 is highly recommended.

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APPENDIX A

COMPUTER PROGRAMS

THEISE I

DATA ACQUISITION PROGRAM

```
2000  DIM D(1101),T(1101),S(1101)
2020  INTEGER N,I
2040  LET N=1
2080  DISP "IS THIS YOUR FIRST DATA SET OUT OF THE 100 DATA SET?"
2100  DISP "PRESS 0 IF YES ; PRESS 1 IF NO"
2120  INPUT ANS
2140  IF ANS=1 THEN GOSUB READ_DATA
2240  DIM I$[5],D$[20000],N$[40]
2260  CONTROL 10,3 ; 15
2280  CONTROL 10,4 ; 58
2300  CONTROL 10,2 ; 1
2320  DISP "PRESS 3091 BUTTON"
2340  ENTER 10 ; I$
2360  ENTER 10 ; D$
2380  ENTER 10 ; N$
2400  H0=VAL (N$[16,20])
2420  V1=(VAL (N$[21,25])-5)*10^(VAL (N$[26,30])-12)
2440  H1=(VAL (N$[31,35])-5)*10^(VAL (N$[36,40])-12)
2460  J=1
2480  K=5
2500  PRINT "N=",N
2520  FOR I=0 TO 1200
2525  IF I<1000 OR I>1100 THEN 2780
2540  D(I)=VAL (D$[J,K])*V1
2560  T(I)=(I-H0)*H1
2580  D(I)=D(I)^2
2600  IF N=1 THEN GOTO 2640
2620  S(I)=((N-1)*S(I)+D(I))/N
2640  IF N=1 THEN S(I)=D(I)
2660  IF I=1000 THEN 2760 ELSE 2680
2680  IF I=1010 THEN 2760 ELSE 2700
2700  IF I=1040 THEN 2760 ELSE 2720
2720  IF I=1050 THEN 2760 ELSE 2740
2740  IF I=1100 THEN 2760 ELSE 2780
2760  DISP T(I);"SEC   ";D(I);"VOLT   ";S(I)
2770  PRINT T(I);"SEC   ";D(I);"VOLT    ";S(I)
2780  J=J+5
2800  K=K+5
2820  NEXT I
2840  N=N+1
2860  IF N=101 THEN GOTO 2761
2700  DISP "DO YOU HAVE ANOTHER SET OF DATA TO COLLECT?"
2920  DISP "PRESS 0 IF YES ; PRESS 1 IF NO"
2740  INPUT YES
2960  IF YES=0 THEN GOTO 2240
2761  IF ANS=1 THEN 2780
2970  CREATE "DATA17",200,8
2971  CREATE "COUNT17",1,8
2972  CREATE "TIME17",200,8
2780  GOSUB WRITE_DISK
3000  END
```

THEISE I Continued

```
3500  WRITE_DISK:
3510  PURGE "DATA17"
3520  CREATE "DATA17",200,8
3540  ASSIGN# 1 TO  "DATA17"
3550  PURGE "COUNT17"
3560  CREATE "COUNT17",1,8
3580  ASSIGN# 2 TO  "COUNT17"
3590  PURGE "TIME17"
3600  CREATE "TIME17",200,8
3620  ASSIGN# 3 TO  "TIME17"
3640  PRINT# 2 : N
3660  FOR I=1000 TO 1100
3680  PRINT# 3 : T(I)
3700  PRINT# 1 : S(I)
3720  NEXT I
3740  ASSIGN# 1 TO  *
3760  ASSIGN# 2 TO  *
3780  ASSIGN# 3 TO  *
3800  RETURN
4000  READ_DATA:
4020  ASSIGN# 2 TO  "COUNT17"
4040  ASSIGN# 1 TO  "DATA17"
4060  READ# 2 : N
4061  PRINT N
4080  FOR I=1000 TO 1100
4100  READ# 1 : S(I)
4120  IF I=1000 THEN 4220 ELSE 4140
4140  IF I=1010 THEN 4220 ELSE 4160
4160  IF I=1040 THEN 4220 ELSE 4180
4180  IF I=1050 THEN 4220 ELSE 4200
4200  IF I=1100 THEN 4220 ELSE 4240
4220  PRINT S(I)
4240  NEXT I
4260  ASSIGN# 1 TO  *
4280  ASSIGN# 2 TO  *
4380  RETURN
```

MAXI

LOCAL MAXIMUM DETERMINATION

```
1000  ASSIGN# 1 TO  "DATA"
1020  ASSIGN# 3 TO  "TIME"
1040  CREATE "NUMBER",1,8
1060  ASSIGN# 4 TO  "NUMBER"
1080  CREATE "TIME_MAX",100,8
1100  ASSIGN# 5 TO  "TIME_MAX"
1120  CREATE "MAXIMUM_S",100,8
1140  ASSIGN# 6 TO  "MAXIMUM_S"
1160  DIM S(1001),T(1001),TIM(100),MAXS(100)
1180  INTEGER I,J
1200  FOR I=822 TO 983
1220  READ# 3 : T(I)
1240  READ# 1 : S(I)
1260  NEXT I
1280  LET J=0
1300  IF S(822) >= S(823) THEN 1320 ELSE 1500
1320     TIM(J)=T(822)
1340     MAXS(J)=SQR (S(822))
1360  PRINT# 5 : TIM(J)
1380  PRINT# 6 : MAXS(J)
1400  PRINT "J=";J;"T=";TIM(J);"      ";MAXS(J)
1420  ! PRINT TIM(J)
1440  ! PRINT MAXS(J)
1460     J=J+1
1480  !
1500  FOR I=823 TO 982
1520     IF S(I) >= S(I-1) AND S(I)>= S(I+1) THEN 1540 ELSE 1720
1540         TIM(J)=T(I)
1560         MAXS(J)=SQR (S(I))
1580  !
1600  PRINT "J=";J;"T=";TIM(J);"     ";MAXS(J)
1620  ! PRINT TIM(J)
1640  ! PRINT MAXS(J)
1660  PRINT# 5 : TIM(J)
1680  PRINT# 6 : MAXS(J)
1700  J=J+1
1720  NEXT I
1730  J=J-1
1740  PRINT# 4 : J
1760  ASSIGN# 4 TO  *
1800  ASSIGN# 5 TO  *
1820  ASSIGN# 6 TO  *
1840  ASSIGN# 1 TO  *
1880  ASSIGN# 3 TO  *
1900  END
```

<u>PLOT 1</u>

LOCAL MAXIMUM PLOT

```
1000  CLEAR
1020  GCLEAR
1040  FRAME
1060  LOCATE 20,135,20,95
1080  CSIZE 4
1100  MOVE 40,10
1120  LABEL "TIME (MICRO-SEC)"
1140  PEN UP
1160  MOVE 8,30
1180  DEG
1200  LDIR 90
1220  LABEL "LN((VOLTAGE^2)^1/2)"
1240  PEN UP
1260  DISP "ENTER THE XMIN OF SCALE"
1280  INPUT XMIN
1300  DISP "ENTER XMAX OF SCALE"
1320  INPUT XMAX
1340  DISP "ENTER THE YMIN OF SCALE"
1360  INPUT YMIN
1380  DISP "ENTER THE YMAX OF SCALE "
1400  INPUT YMAX
1420  SCALE XMIN,XMAX,YMIN,YMAX
1440  FXD 0,2
1460  DISP "ENTER THE X-TICKING SPACE"
1480  INPUT XT
1500  DISP "ENTER THE Y-TICKING SPACE"
1520  INPUT YT
1540  DISP "ENTER THE X INTERSECTION"
1560  INPUT XI
1580  DISP "ENTER THE Y INTER SECTION"
1600  INPUT YI
1620  DISP "ENTER THE X-MAJOR COUNT"
1640  INPUT XMC
1660  DISP "ENTER THE Y-MAJOR COUNT"
1680  INPUT YMC
1700  LAXES XT,YT,XI,YI,XMC,YMC
1710  GRAPH
1720   PEN 1
1740  DIM TIM(100),MAXS(100)
1741  DIM TIMEMAX$[20],MAXIMUM$[20]
1742  DISP "WHAT IS YOUR FILE NAME FOR TIMEMAX$ ?"
1744  INPUT TIMEMAX$
1746  DISP "WHAT IS YOUR FILE NAME FOR MAXIMUM$ ?"
1748  INPUT MAXIMUM$
1749  PRINT "THE DATA FILES ARE",TIMEMAX$,"AND",MAXIMUM$
1750  DISP "WHAT IS THE HIGHEST ORDER OF ARRAY NUMBER?"
1752  INPUT J1
1760  ASSIGN# 5 TO  TIMEMAX$
1780  ASSIGN# 6 TO  MAXIMUM$
```

PLOT 1 Continued

```
1781  DISP "PRESS 0 IF THE FIRST LOCAL MAXIMUM IS BEING SAVED ?"
1782  INPUT OK
1790  FOR I=0 TO JK
1800  READ# 5 ; TIM(I)
1810  TIM(I)=TIM(I)*1000000
1820  READ# 6 ; MAXS(I)
1821  MAXS(I)=LOG (MAXS(I))
1823  NEXT I
1825  K=JK+1
1826  IF OK=0 THEN GOTO 1835
1828  FOR I=1 TO JK
1831  TIM(I-1)=TIM(I)
1832  MAXS(I-1)=MAXS(I)
1833  NEXT I
1834  K=JK
1835  ! DISP "WHICH CHARACTER YOU PREFER TO USING IN PLOTTING THE DATA"
1837  ! INPUT C$
1839  MOVE TIM(0),MAXS(0)
1840  FOR I=0 TO K-1
1920  DRAW TIM(I),MAXS(I)
1930  ! LABEL C$
1940  NEXT I
1960  PEN UP
1962  GOSUB LEASTSQR
1980  ASSIGN# 5 TO  *
2000  ASSIGN# 6 TO  *
2020  END
3000  LEASTSQR:
3040  REAL Y,XY,X1,X2,TAVE,YAVE,VARX,VARY,COVXY
3060  LET Y=0
3080  !        Y IS THE SUMMATION OF Y(I) VALUE
3100  LET XY=0
3120  !        XY IS THE SUMMATION OF X(I)*Y(I)
3140  LET X1=0
3160  !        X1 IS THE SUMMATION OF X(I)
3180  LET X2=0
3200  !        X2 IS THE SUMMATION OF X(I) 2
3220  FOR I=0 TO K-1
3240  Y=Y+MAXS(I)
3260  XY=XY+TIM(I)*MAXS(I)
3280  X1=X1+TIM(I)
3300  X2=X2+TIM(I) 2
3320  NEXT I
3340  B=(X2*Y-X1*XY)/(K*X2-X1 2)
3350  !
3351  !
3352  !       A IS THE SLOPE OF THE FITTED STRAIGHT LIGHT
3360  A=(K*XY-X1*Y)/(K*X2-X1 2)
3370  !
3371  !
3372  !       B IS THE INTERCEPT TO Y AXIS
3380  PRINT "THE SLOPE A=";A
3400  PRINT "THE Y-INTERCEPT B=";B
3420  YAVE=(MAXS(0)+MAXS(K-1))/2
3440  TAVE=(TIM(0)+TIM(K-1))/2
```

```
3460  COVXY=0
3461  '
3480  '       COVXY IS THE COVARIANCE OF  TIME AND VOLTAGE (LN)
3481  '
3500  VARX=0
3520  '       VARX IS THE VARIANCE OF TIME VARIABLE
3521  '
3540  VARY=0
3560  '       VARY IS THE VARIANCE OF VOLTAGE(LN) VARIABLE
3561  !
3562  DIM YL(100)
3580  FOR I=0 TO K-1
3600  !
3620  COVXY=COVXY+(TIM(I)-TAVE)*(MAXS(I)-YAVE)
3640  '
3660  VARX=VARX+(TIM(I)-TAVE)^2
3680  '
3700  VARY=VARY+(MAXS(I)-YAVE)^2
3720  '
3740  YL(I)=A*TIM(I)+B
3760  !       YL IS THE VALUE FITTED ON THE STRAIGHT LINE
3761  '
3780  NEXT I
3800  PEN 2
3820  MOVE TIM(0),YL(0)
3840  FOR I=0 TO K-1
3860  DRAW TIM(I),YL(I)
3880  NEXT I
3900  CORCOE=COVXY/SQR (VARX*VARY)
3920  '       CORCOE IS THE CORRELATION COEFFICIENT
3940  '
3960  PRINT "CORRELATION COEFFICIENT IS ";CORCOE
3980  RETURN
```

PLOT

AVERAGED POINT PLOT

```
1000  CLEAR
1020  GCLEAR
1040  FRAME
1060  LOCATE 20,135,20,95
1080  CSIZE 4
1100  MOVE 40,10
1120  LABEL "TIME  (MICRO-SECOND) "
1140  PEN UP
1160  MOVE 8,30
1180  DEG
1200  LDIR 90
1220  LABEL "LN((VOLTAGE 2) 1/2)"
1240  PEN UP
1241  DISP "DO YOU WANT TO USE THE DEFAULT SCALE SET UP ?   YES = 0"
1242  INPUT BULL
1243  IF BULL=0 THEN 1244 ELSE 1260
1244  SCALE 820,970,-5,2
1245  FXD 0,2
1246  LAXES 10,.5,820,-5,2,2
1250  IF BULL=0 THEN 1460
1260  DISP "ENTER THE XMIN OF SCALE"
1280  INPUT XMIN
1300  DISP "ENTER XMAX OF SCALE"
1320  INPUT XMAX
1340  DISP "ENTER THE YMIN OF SCALE"
1360  INPUT YMIN
1380  DISP "ENTER THE YMAX OF SCALE "
1400  INPUT YMAX
1420  SCALE XMIN,XMAX,YMIN,YMAX
1440  FXD 0,2
1460  DISP "ENTER THE X-TICKING SPACE"
1480  INPUT XT
1500  DISP "ENTER THE Y-TICKING SPACE"
1520  INPUT YT
1540  DISP "ENTER THE X INTERSECTION"
1560  INPUT XI
1580  DISP "ENTER THE Y INTER SECTION"
1600  INPUT YI
1620  DISP "ENTER THE X-MAJOR COUNT"
1640  INPUT XMC
1660  DISP "ENTER THE Y-MAJOR COUNT"
1680  INPUT YMC
1700  LAXES XT,YT,XI,YI,XMC,YMC
1710  GRAPH
1720   PEN 1
1730  DIM VDATA$[20],TTIME$[20]
1731  DISP "INPUT THE DATA# FILE NAME "
1732  INPUT VDATA$
1733  DISP "INPUT THE TIME# FILE NAME "
1734  INPUT TTIME$
1740  DIM T(1001),S(1001)
1760  ASSIGN# 1 TO  VDATA$
1780  ASSIGN# 2 TO  TTIME$
```

PLOT Continued

```
1782  DISP "ENTER THE STARTING DATA COLLECTING TIME"
1784  INPUT START
1786  DISP "ENTER THE ENDING DATA COLLECTING TIME"
1788  INPUT ENDT
1790  FOR I=START TO ENDT
1800  READ# 1 ; S(I)
1810  S(I)=SQR (S(I))
1820  READ# 3 ; T(I)
1825  NEXT I
1830  MOVE T(START)*1000000,LOG (S(START))
1840  FOR I=START TO ENDT
1860  MAXS=LOG (S(I))
1880  X=T(I)*1000000
1900  Y=MAXS
1920  DRAW X,Y
1940  NEXT I
1950  PEN UP
1960  ASSIGN# 1 TO  *
1980  ASSIGN# 3 TO  *
2000  END
```

APPENDIX B
PRELIMINARY TESTS

TABLE 1
BEAM PATTERN

FREQUENCY = 180 kHz

DIRECTION (DEG.)	VOLTAGE (mV)	dB
000	300.2	0.00
005	193.0	-3.84
010	46.65	-16.17
012.5	7.78	-31.72
015	46.25	-16.24
017.5	54.05	-14.89
020	39.05	-17.72
022.5	18.55	-24.18
025	29.50	-20.15
030	63.80	-13.45
035	42.75	-16.90
040	28.85	-20.34
045	24.00	-21.94
050	20.05	-23.50
055	17.78	-24.50
060	13.25	-27.10
065	8.58	-30.90
070	5.53	-34.70
075	3.28	-39.20
080	2.75	-40.80
085	1.80	-44.40
090	1.70	-44.90
095	1.50	-46.00
100	0.98	-49.70

Table 1 continued

DIRECTION (DEG.)	VOLTAGE (mV)	dB
105	1.30	-47.30
110	2.35	-42.10
115	1.33	-47.10
120	1.78	-44.50
125	1 33	-47.10
130	2.45	-41.80
135	3.53	-38.60
140	8.33	-31.10
145	9.28	-30.20
150	7.23	-32.40
155	4.78	-36.00
160	8.03	-31.40
165	2.43	-41.80
170	14.05	-26.60
175	19.40	-23.80
180	21.90	-22.70
185	11.05	-28.68
190	3.53	-38.59
195	9.40	-30.09
200	5.15	-35.31
205	10.78	-28.90
210	11.15	-28.60
215	7.60	-31.93
220	2.63	-41.15
225	2.43	-41.84
230	1.23	-47.75
235	1.95	-43.75
240	1.53	-45.85
245	1.90	-43.97
250	1.80	-44.44

Table 1 continued

DIRECTION (DEG.)	VOLTAGE (mV)	dB
255	1.98	-43.61
260	2.65	-41.08
265	1.75	-44.69
270	1.80	-44.44
275	3.00	-40.00
280	3.38	-38.97
285	5.23	-35.18
290	9.03	-30.43
295	14.30	-26.44
300	23.10	-22.27
305	26.40	-21.12
310	22.70	-22.43
315	19.10	-23.93
320	33.10	-19.15
325	53.60	-14.96
330	50.55	-19.55
335	31.60	-28.96
337.5	10.70	-15.47
340	25.25	-21.50
345	54.00	-14.89
350	11.23	-28.54
355	130.00	-7.23
360	300.20	0.00

TABLE 2

NEAR FIELD

DISTANCE (cm)	VOLTAGE (V)
15.0	0.44
20.0	0.36
25.0	0.36
30.0	0.40
35.0	0.42
40.0	0.44
45.0	0.44
50.0	0.44
55.0	0.40
60.0	0.36
65.0	0.36
70.0	0.33
75.0	0.31
80.0	0.31
85.0	0.28
90.0	0.27
100.0	0.23
110.0	0.24
120.0	0.20
130.0	0.20
140.0	0.19
150.0	0.16

TABLE 3

SPEED OF SOUND IN WATER

DISTANCE (cm) ($r_2 - r_1$)	TIME (μ s)	Amplitude (mV) (FIXED)	(MOBILE)	SOUND SPEED (m/s)
12.0	82	119.1	145.3	1463.4
14.0	98	"	129.1	1428.6
16.0	112	"	53.4	1428.5
18.0	124	"	58.0	1451.6
20.0	142	"	55.9	1408.5
22.0	150	"	85.1	1466.7
24.0	164	"	91.1	1463.4
26.0	178	"	95.7	1460.6
28.0	190	"	78.1	1473.6
30.0	204	"	82.2	1470.6
32.0	270	"	82.3	1454.5
34.0	232	"	106.0	1465.5

$\bar{c}$ = 1453 m/s

σ = 20 m/s

TABLE 4

SPEED OF SOUND IN AGGREGATE

DISTANCE (cm) $(r_2 - r_1)$	TIME (μ s)	AMPLITUDE (mv) (Fixed)	(MOBILE)	SOUND SPEED (m/s)
15.0	86	29.05	16.05	1744
18.2	108	"	19.55	1685
20.2	124	"	17.40	1629
22.0	144	"	12.00	1528
24.0	160	"	12.00	1500
25.9	176	"	14.25	1472
28.0	182	"	10.65	1538
29.8	188	"	10.55	1585
31.0	198	"	9.10	1566
32.0	202	"	9.05	1584

$\overline{c}$ = 1583 m/s

σ = 84 m/s

APPENDIX C
REFLECTION COEFFICIENT AND DENSITY MEASUREMENTS

TABLE 1

NORMAL PRESSURE REFLECTION COEFFICIENT FOR FINE SAND

WATER DEPTH (cm)	V_1 (mV)	V_2 (mV)	R
30	4.18	1.44	0.35
35	6.83	2.40	0.35
40	4.72	1.85	0.38

NORMAL PRESSURE REFLECTION COEFFICIENT FOR AGGREGATE

WATER DEPTH (cm)	V_1 (mV)	V_2 (mV)	R
25	786.0	214.0	0.27
30	752.0	210.0	0.28
35	836.0	216.0	0.26

TABLE 2

DENSITY MEASUREMENTS IN AGGREGATE

OBSERVATIONS	MASS OF DRY SEDIMENT (g)	MASS OF SEDIMENT/ WATER MIXTURE (g)	VOLUME OF SEDIMENT TO WATER (ml)	MEASURED DENSITY OF MIXTURE (g/cm^3)
1	158.85	198.60	59	1.99
2	154.40	196.00	59	1.96
3	154.05	194.20	59	1.94
4	158.35	202.66	59	2.03
5	156.05	195.35	60	1.95
6	155.95	196.30	59	1.96
7	153.25	193.90	60	1.94
8	153.85	195.60	58	1.96
9	157.45	198.20	58	1.98
10	156.45	196.80	59	1.97

$\bar{\rho}_{mix}$ = 1.97 g/cm^3

σ = 0.03 g/cm^3

ρ_{dry} = 2.64 g/cm^3 (computed)

Average Porosity of Sediment = 59%

APPENDIX D
RESULTS

TABLE 1

WATER/AIR REFLECTION

FREQUENCY: 185kHz

DATA SET	SAMPLE TIME (μs)	NUMBER OF SAMPLES IN DATA SET	SLOPE ($x10^{-2}$)	CORRELATION COEFFICIENT
DATA3	840-983	50	-3.7566	-0.9894
DATA4	" "	25	-3.7861	-0.9967
DATA6	" "	100	-3.6911	-0.9728
DATA7	" "	5	-4.0184	-0.9985
DATA8	" "	10	-3.9628	-0.9876
DATA9	" "	25	-3.9688	-0.9920
DATA10	" "	50	-3.5874	-0.9801
DATA11	" "	50	-3.9209	-0.9986

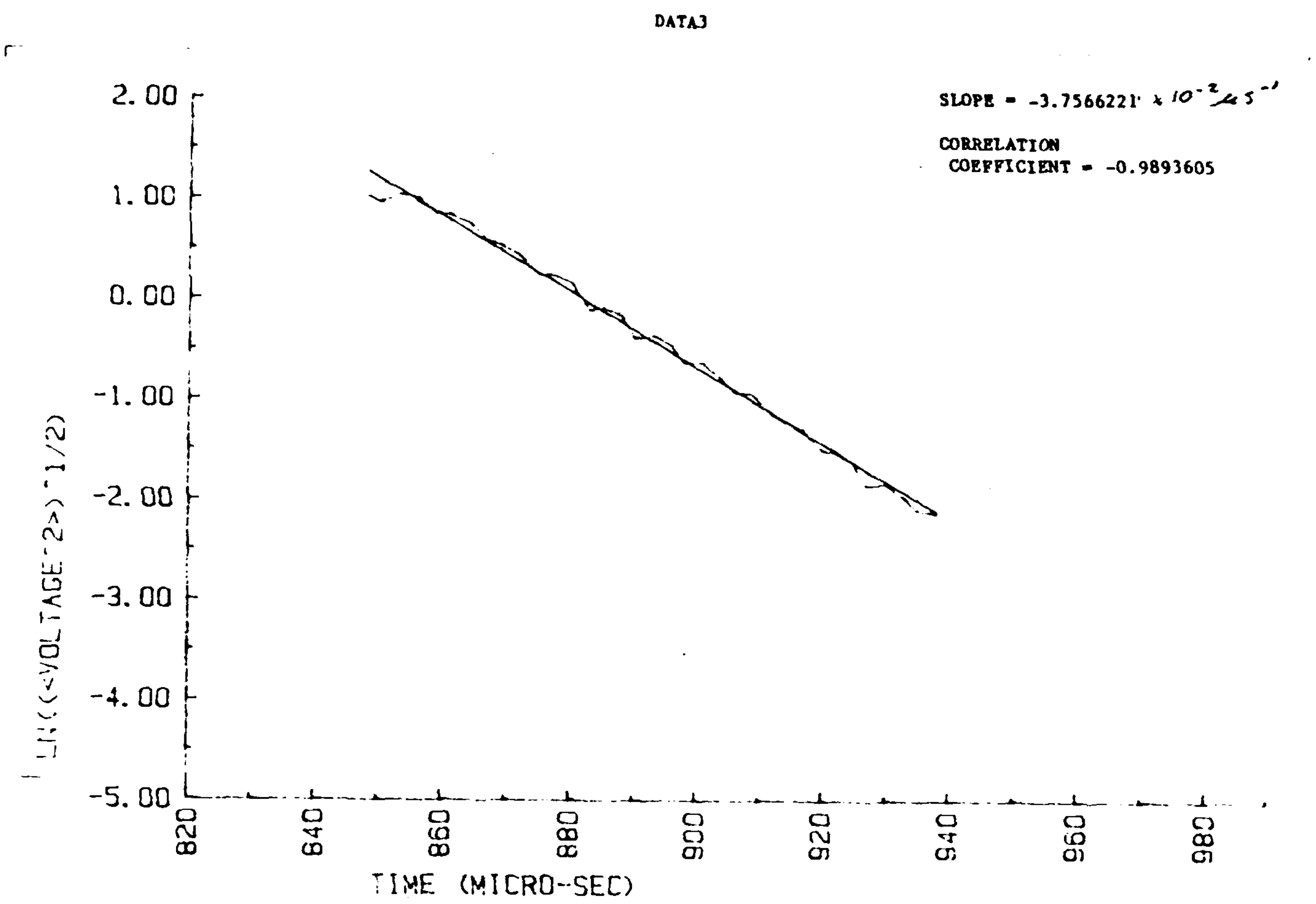
MEAN SLOPE = $-3.84 \times 10^{-2}\ \mu s^{-1}$

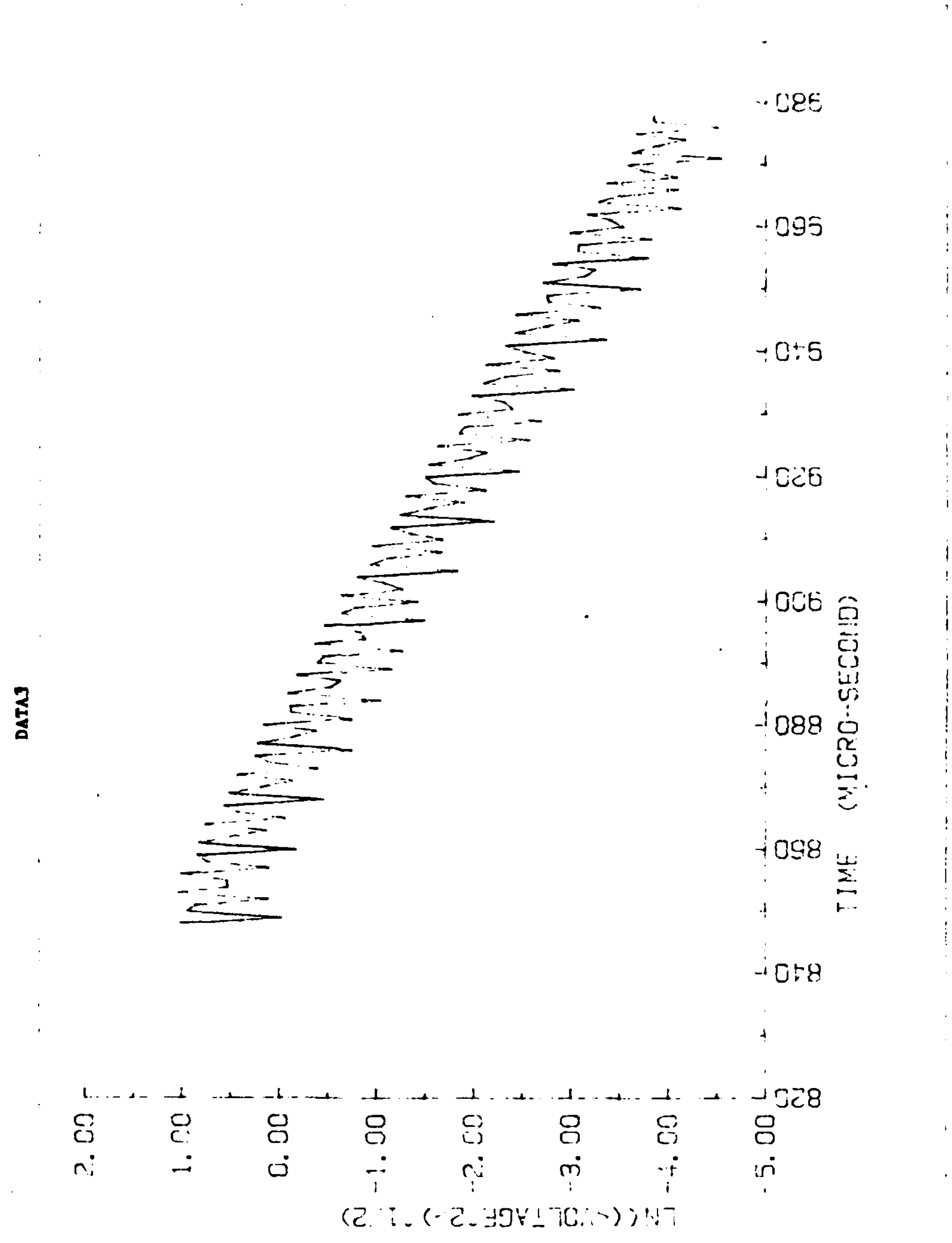
$\sigma = 0.14 \times 10^{-2}\ \mu s^{-1}$

DATA3

LOCAL MAXIMA

		TIME (SEC.)	VOLT
J=	1	.000850	2.59613424
J=	2	.000853	2.79951389
J=	3	.000856	2.71931729
J=	4	.000859	2.30353012
J=	5	.000861	2.28819448
J=	6	.000864	2.12830884
J=	7	.000867	1.75489017
J=	8	.000869	1.69369035
J=	9	.000872	1.53057604
J=	10	.000875	1.26327075
J=	11	.000877	1.25842342
J=	12	.000880	1.16341394
J=	13	.000883	.88792004
J=	14	.000885	.91407904
J=	15	.000888	.83815154
J=	16	.000890	.67148380
J=	17	.000893	.69302453
J=	18	.000896	.62557893
J=	19	.000898	.52693121
J=	20	.000901	.52798153
J=	21	.000904	.44685568
J=	22	.000906	.39219574
J=	23	.000909	.38373103
J=	24	.000912	.31615344
J=	25	.000914	.29276868
J=	26	.000917	.27238943
J=	27	.000920	.22175888
J=	28	.000922	.21624870
J=	29	.000925	.19514738
J=	30	.000927	.15660140
J=	31	.000930	.15839034
J=	32	.000933	.13726616
J=	33	.000935	.12214950
J=	34	.000938	.11817995
J=	35	.000941	.09757817
J=	36	.000943	.08842511
J=	37	.000946	.08691950
J=	38	.000949	.06372598
J=	39	.000951	.06676077
J=	40	.000954	.06005831
J=	41	.000956	.04650806
J=	42	.000959	.05024440
J=	43	.000962	.04182105
J=	44	.000964	.03720887
J=	45	.000967	.03414674
J=	46	.000970	.02744085
J=	47	.000972	.02630589
J=	48	.000975	.02539685

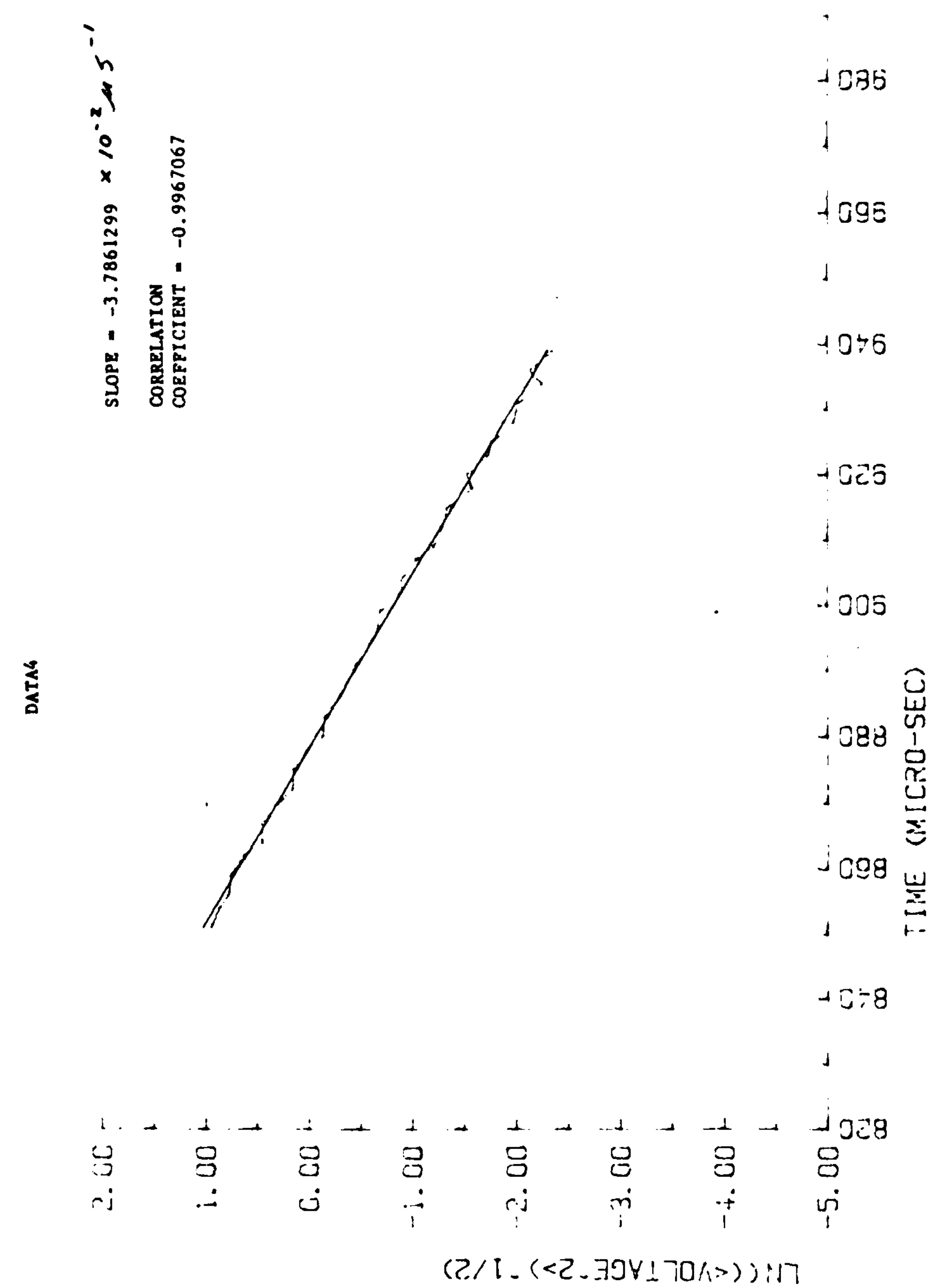

DATA3
SLOPE = -3.7566221 x 10^-2 µs^-1
CORRELATION
COEFFICIENT = -0.9893605
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
LN((<VOLTAGE^2>)^1/2)
820
840
860
880
900
920
940
960
980
TIME (MICRO-SEC)


DATA3
TIME (MICRO-SECOND)
820
840
860
880
900
920
940
960
980
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00

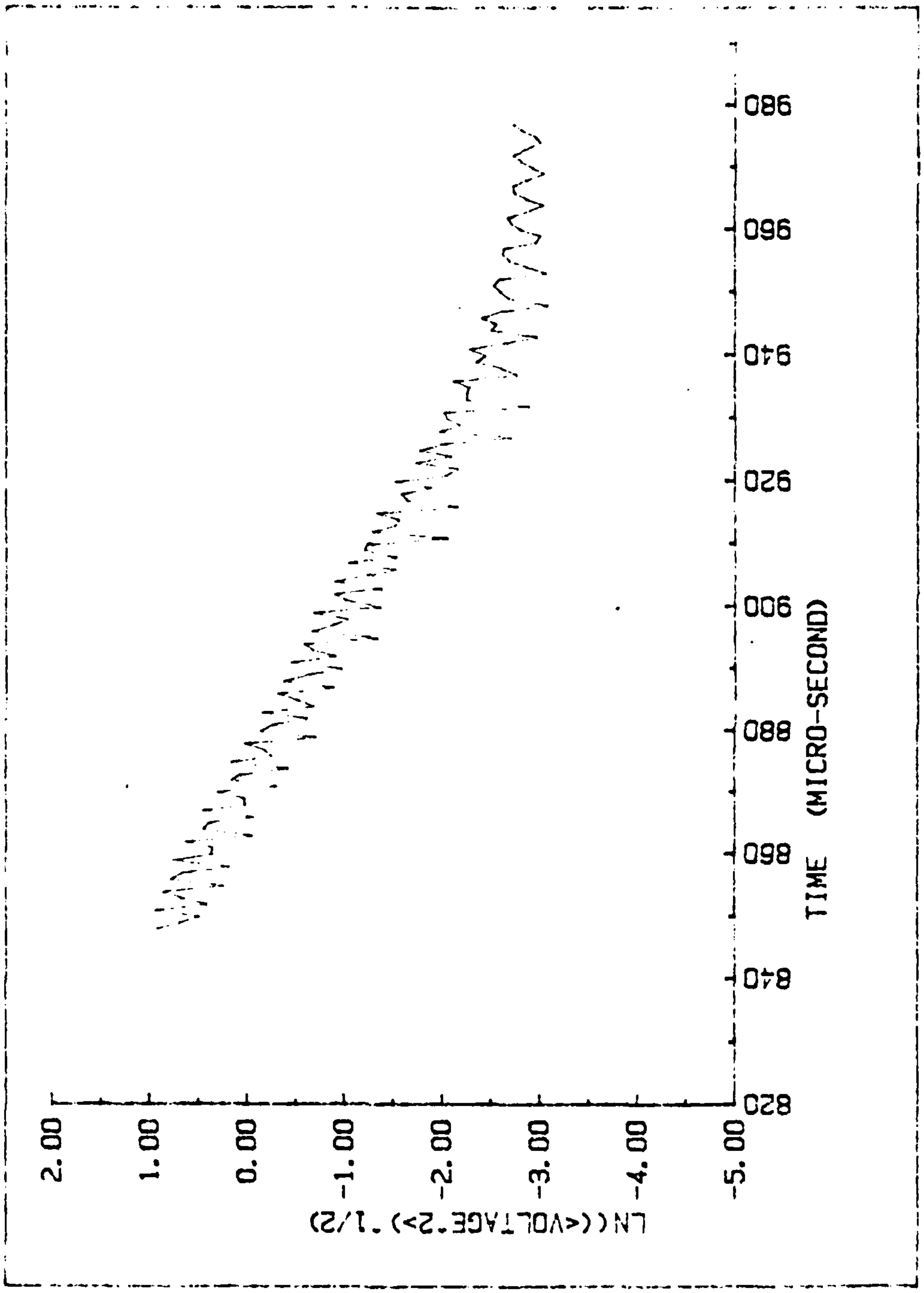
DATA4

LOCAL MAXIMA

		TIME (SEC.)	VOLT
J=	1	.000851	2.56653872
J=	2	.000854	2.36947695
J=	3	.000856	2.16645909
J=	4	.000859	2.12358306
J=	5	.000862	1.87433321
J=	6	.000864	1.56400352
J=	7	.000867	1.58445764
J=	8	.000870	1.34618869
J=	9	.000872	1.16810744
J=	10	.000875	1.16227277
J=	11	.000878	1.01832215
J=	12	.000880	.86677852
J=	13	.000883	.85511695
J=	14	.000886	.73137337
J=	15	.000888	.68510510
J=	16	.000891	.63408674
J=	17	.000894	.55311301
J=	18	.000896	.51156720
J=	19	.000899	.50001800
J=	20	.000902	.40213431
J=	21	.000904	.40505061
J=	22	.000907	.34963123
J=	23	.000909	.29629884
J=	24	.000912	.27229580
J=	25	.000915	.26062041
J=	26	.000918	.20316496
J=	27	.000920	.21664718
J=	28	.000923	.17491426
J=	29	.000925	.16858826
J=	30	.000928	.13725888
J=	31	.000931	.13128214
J=	32	.000934	.10402404
J=	33	.000936	.11898319
J=	34	.000939	.09447222
J=	35	.000941	.10088607
J=	36	.000944	.08064738
J=	37	.000946	.08919081
J=	38	.000951	.07902531
J=	39	.000956	.07198611
J=	40	.000962	.06824954
J=	41	.000967	.06494613
J=	42	.000972	.06486139



DATA4
SLOPE = -3.7861299 x 10^-2 μs^-1
CORRELATION
COEFFICIENT = -0.9967067
TIME (MICRO-SEC)
LN((<VOLTAGE^2>)^1/2)
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
820
840
860
880
900
920
940
960
980

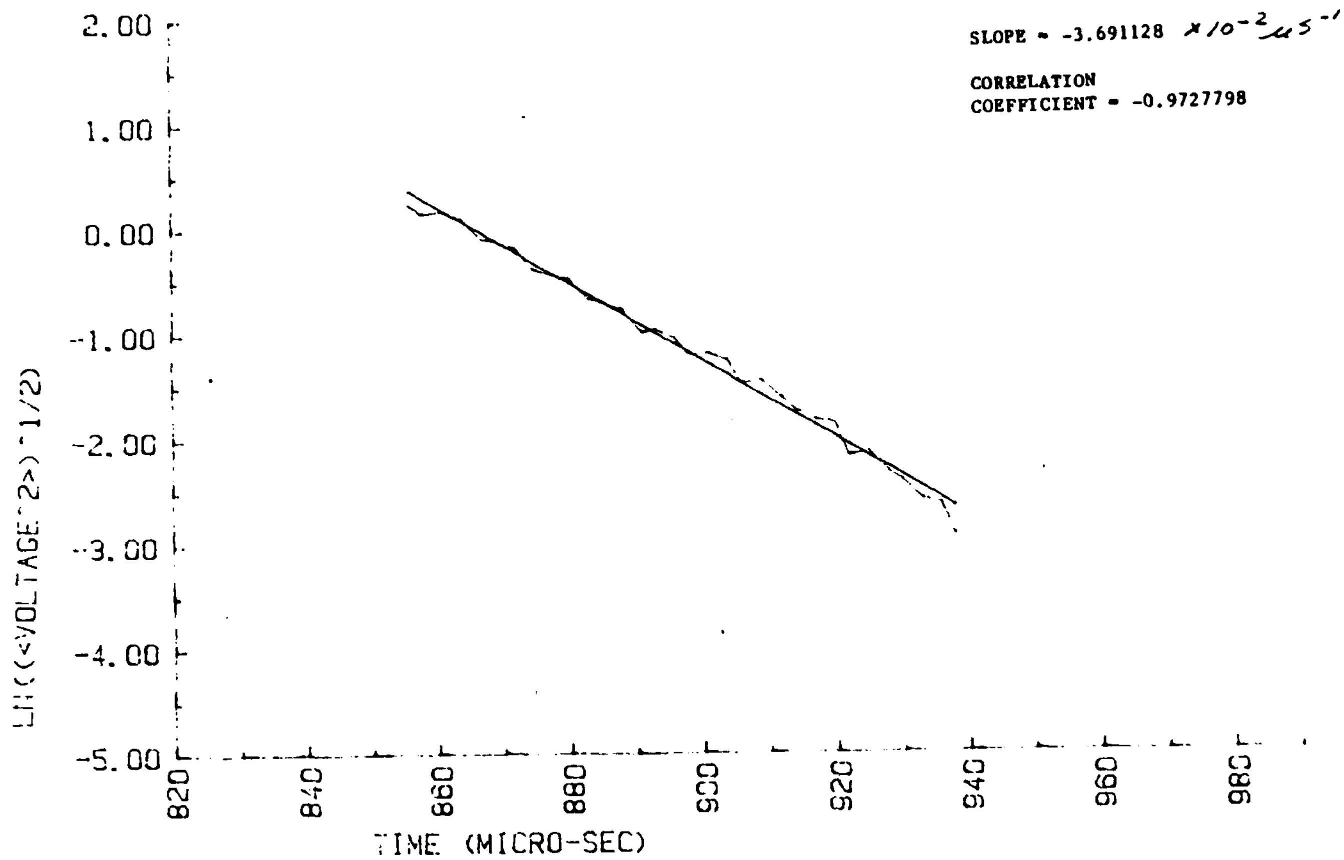

DATA4
LN((<VOLTAGE^2>)^1/2)
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
820
840
860
880
900
920
940
960
980
TIME (MICRO-SECOND)

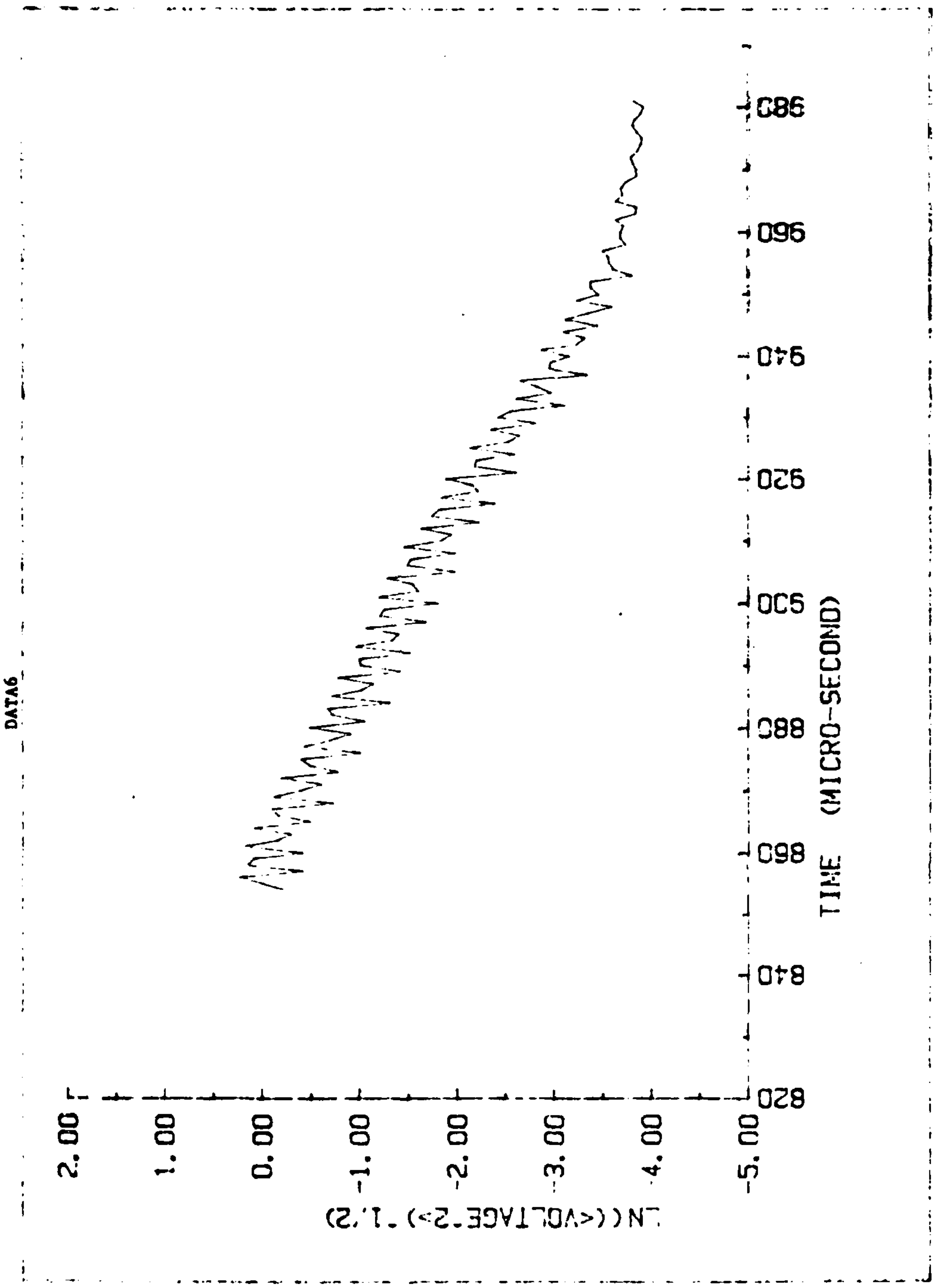
DATA6

LOCAL MAXIMA

	TIME (SEC.)	VOLT
J= 0	.000856	1.25228910
J= 1	.000858	1.15177081
J= 2	.000861	1.18948224
J= 3	.000864	1.09117001
J= 4	.000867	.90368579
J= 5	.000869	.88389592
J= 6	.000872	.82582080
J= 7	.000875	.67306166
J= 8	.000877	.65203988
J= 9	.000880	.61720985
J= 10	.000883	.51030187
J= 11	.000885	.49017548
J= 12	.000888	.45939090
J= 13	.000891	.36963766
J= 14	.000893	.38264866
J= 15	.000896	.34631777
J= 16	.000898	.29783217
J= 17	.000901	.30169521
J= 18	.000904	.27828043
J= 19	.000906	.22592034
J= 20	.000909	.23441843
J= 21	.000912	.19708881
J= 22	.000914	.17593180
J= 23	.000917	.15962456
J= 24	.000920	.15278743
J= 25	.000922	.11290704
J= 26	.000925	.11862546
J= 27	.000928	.09622889
J= 28	.000930	.08890444
J= 29	.000933	.07437742
J= 30	.000936	.07099296
J= 31	.000938	.05306600
J= 32	.000941	.05723635
J= 33	.000944	.04538722
J= 34	.000946	.04454211
J= 35	.000949	.03964846
J= 36	.000952	.03464102
J= 37	.000957	.03052868
J= 38	.000960	.02545584
J= 39	.000962	.02668333
J= 40	.000965	.02660827
J= 41	.000967	.02537716
J= 42	.000972	.02289105
J= 43	.000977	.02244994

DATA6

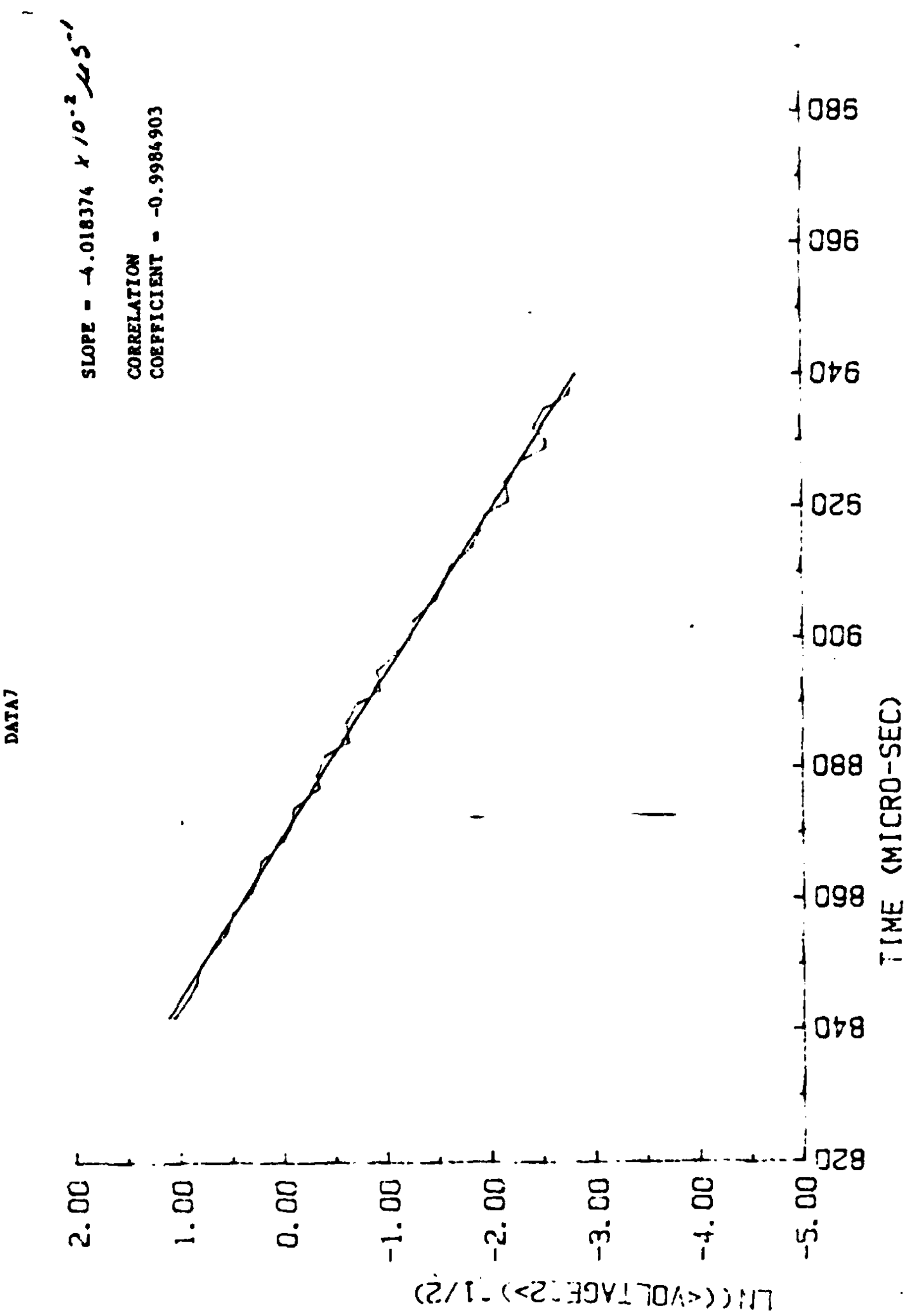

SLOPE = -3.691128 x 10^-2 μs^-1
CORRELATION
COEFFICIENT = -0.9727798
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
LN((<VOLTAGE^2>)^1/2)
820
840
860
880
900
920
940
960
980
TIME (MICRO-SEC)

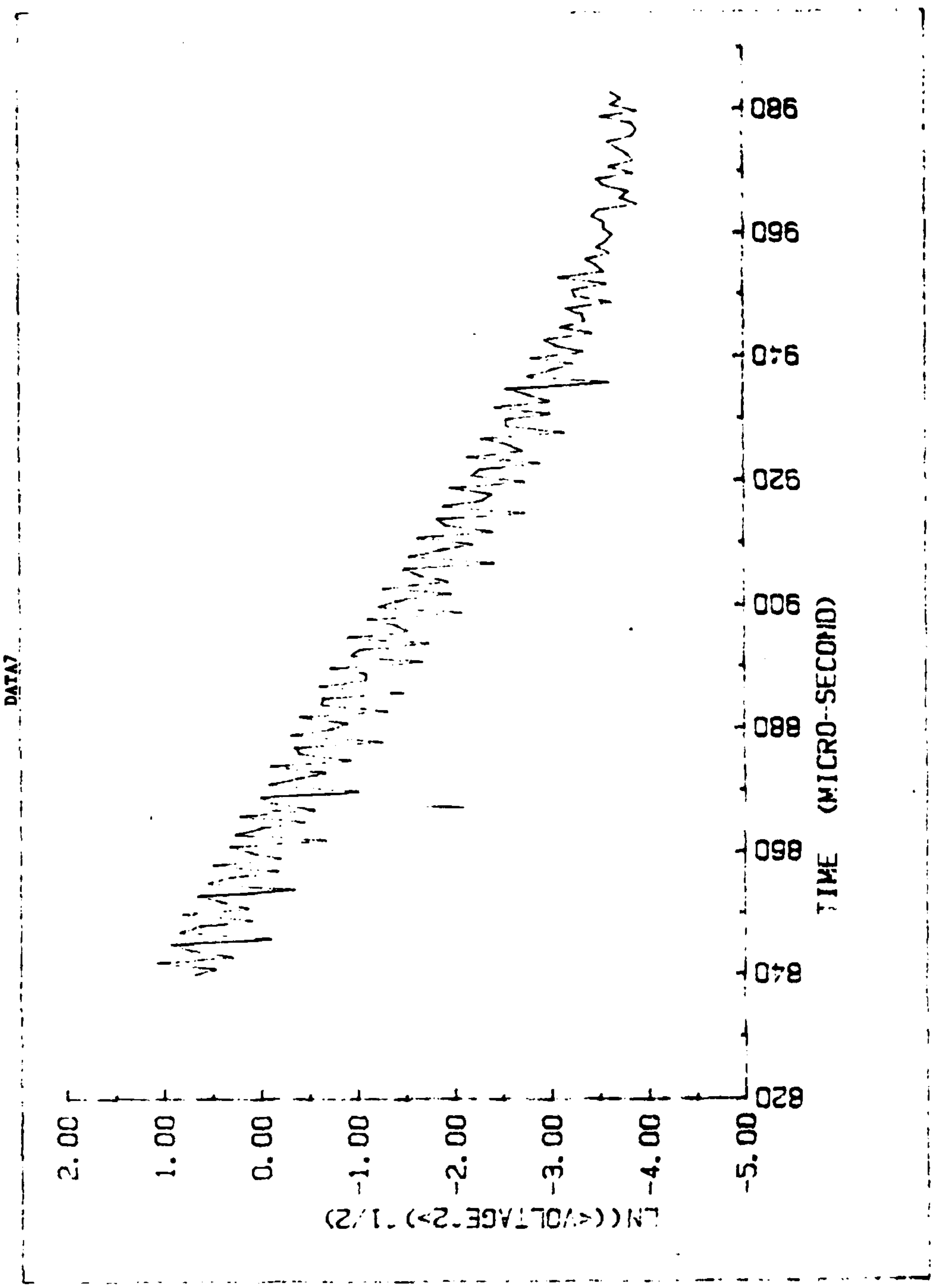

DATA6
LN((<VOLTAGE^2>)^1/2)
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
820
840
860
880
900
920
940
960
980
TIME (MICRO-SECOND)

DATA7

LOCAL MAXIMA

		TIME (SEC.)	VOLT
J=	1	.000842	2.86286570
J=	2	.000845	2.50100780
J=	3	.000847	2.32526128
J=	4	.000850	2.22915231
J=	5	.000853	1.91358303
J=	6	.000855	1.71812689
J=	7	.000858	1.61507895
J=	8	.000861	1.36750868
J=	9	.000863	1.28786645
J=	10	.000866	1.23103209
J=	11	.000869	.99214918
J=	12	.000871	.92762061
J=	13	.000874	.89672738
J=	14	.000877	.69782519
J=	15	.000879	.71769074
J=	16	.000882	.65748004
J=	17	.000884	.52524280
J=	18	.000887	.53844220
J=	19	.000890	.47933287
J=	20	.000892	.38631593
J=	21	.000895	.40139756
J=	22	.000898	.32625144
J=	23	.000900	.29161619
J=	24	.000903	.27683930
J=	25	.000906	.22521101
J=	26	.000908	.21326040
J=	27	.000911	.19503846
J=	28	.000914	.15912259
J=	29	.000916	.14966630
J=	30	.000919	.14014278
J=	31	.000921	.11207141
J=	32	.000924	.11644741
J=	33	.000927	.09979980
J=	34	.000929	.07771744
J=	35	.000930	.07771744
J=	36	.000932	.08763561
J=	37	.000935	.07797435
J=	38	.000937	.06260990
J=	39	.000940	.06000000
J=	40	.000943	.05215362
J=	41	.000945	.04427189
J=	42	.000948	.04147288
J=	43	.000951	.03898718
J=	44	.000953	.04472136
J=	45	.000956	.03405877
J=	46	.000958	.03033150
J=	47	.000963	.03162278
J=	48	.000966	.02366432
J=	49	.000969	.03033150
J=	50	.000971	.02683282
J=	51	.000975	.02683282
J=	52	.000979	.02898275
J=	53	.000981	.02607681

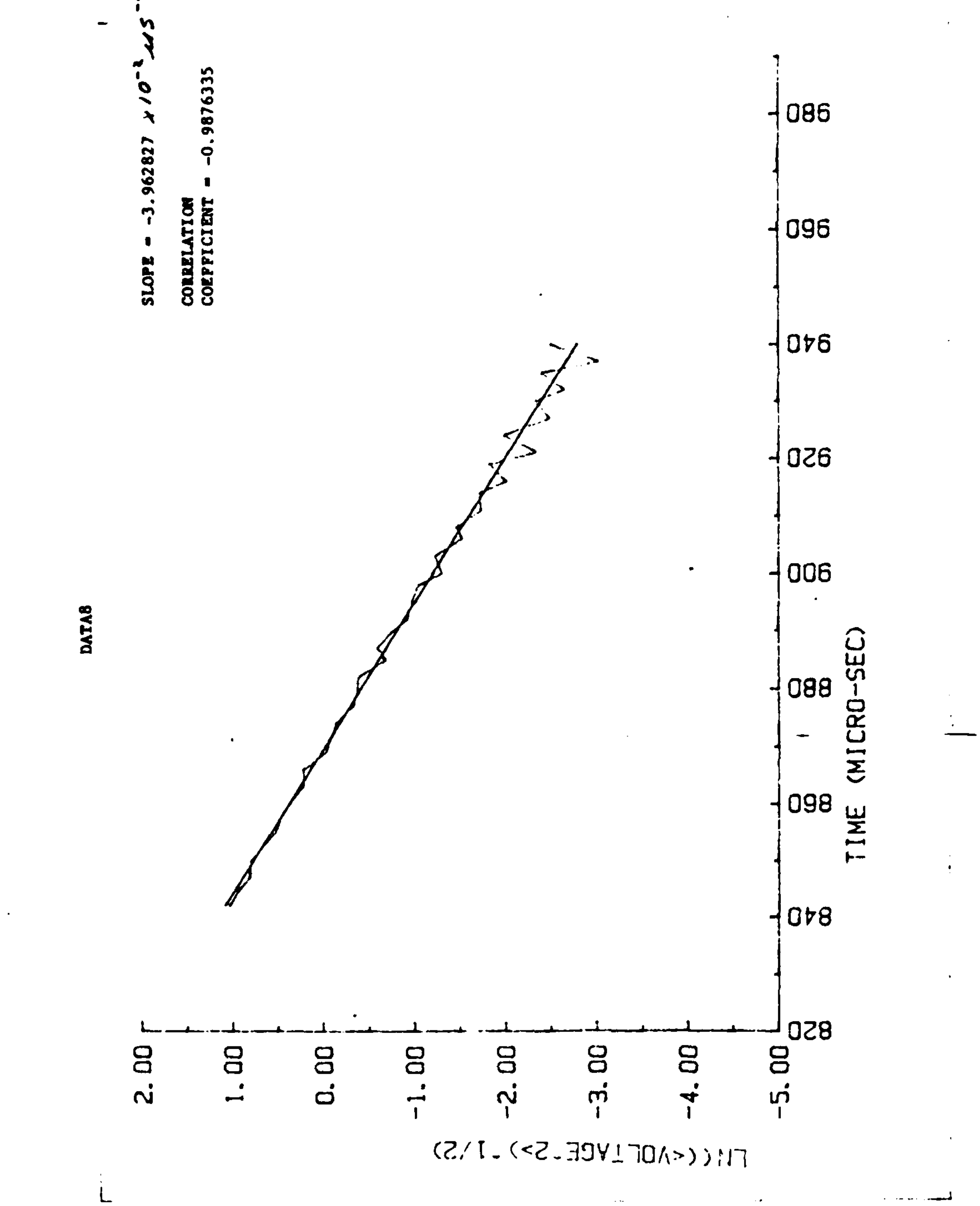

DATA7
SLOPE = -4.018374 x 10^-2 μs^-1
CORRELATION
COEFFICIENT = -0.9984903
TIME (MICRO-SEC)
820
840
860
880
900
920
940
960
980
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00

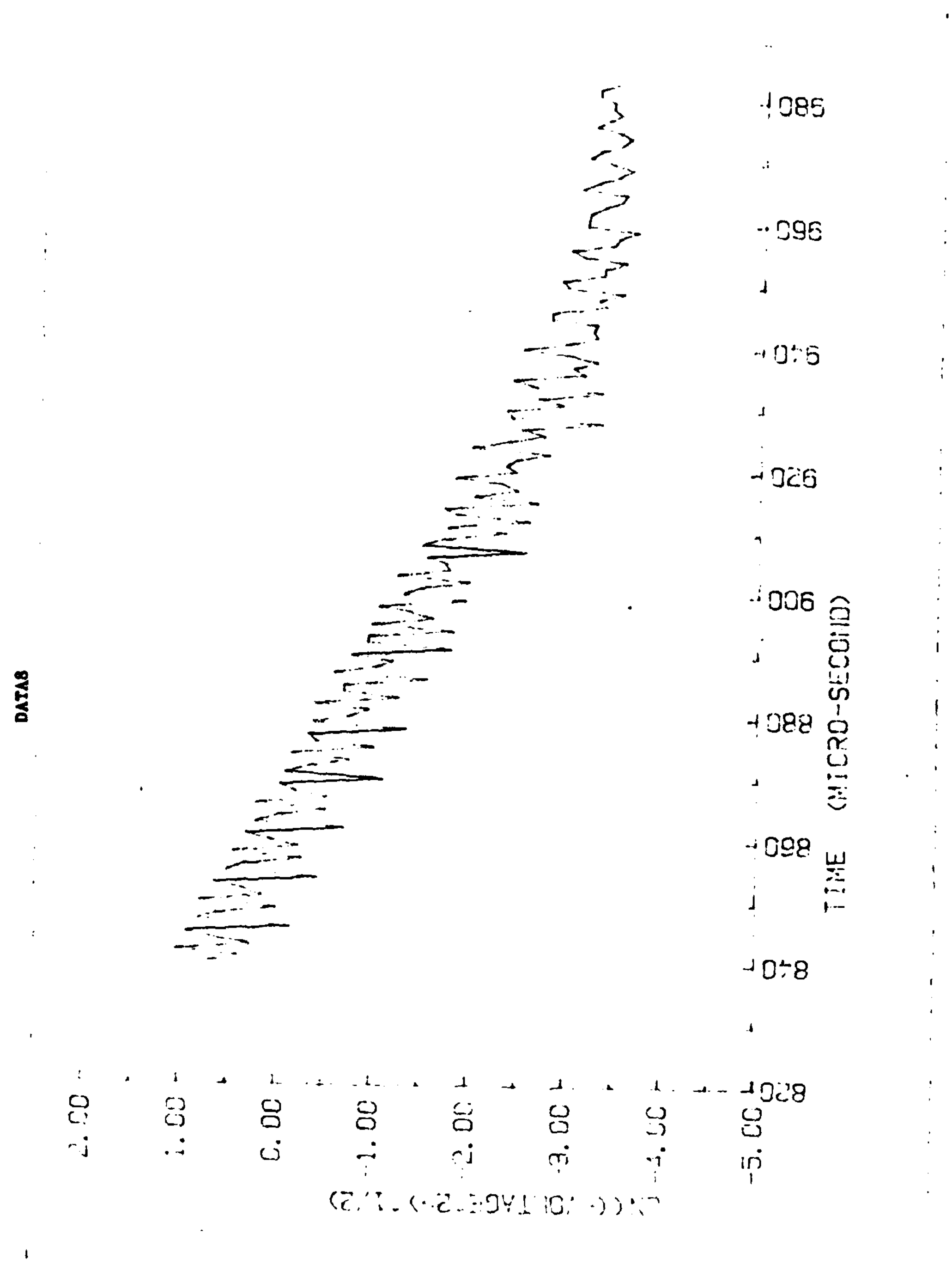

DATA7
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
LN((<VOLTAGE^2>)^1/2)
820
840
860
880
900
920
940
960
980
TIME (MICRO-SECOND)

DATA8

LOCAL MAXIMA

	TIME (SEC.)	VOLT
J= 1	.000842	2.82097855
J= 2	.000845	2.51604451
J= 3	.000847	2.25417391
J= 4	.000850	2.22184608
J= 5	.000853	1.89121654
J= 6	.000855	1.69882901
J= 7	.000858	1.57907568
J= 8	.000861	1.38683813
J= 9	.000863	1.24620223
J= 10	.000866	1.24209500
J= 11	.000869	.97068017
J= 12	.000871	.93496524
J= 13	.000874	.86755980
J= 14	.000877	.71880456
J= 15	.000879	.69228607
J= 16	.000882	.67768724
J= 17	.000885	.50009999
J= 18	.000887	.55375085
J= 19	.000890	.46255810
J= 20	.000892	.39489239
J= 21	.000895	.37884034
J= 22	.000898	.34919908
J= 23	.000900	.27055499
J= 24	.000903	.29305290
J= 25	.000906	.21549942
J= 26	.000908	.22973898
J= 27	.000911	.17567015
J= 28	.000914	.18083141
J= 29	.000916	.13326665
J= 30	.000919	.16204938
J= 31	.000921	.09591663
J= 32	.000924	.13834739
J= 33	.000927	.08282512
J= 34	.000930	.09705668
J= 35	.000932	.07014271
J= 36	.000935	.09099451
J= 37	.000937	.04857983
J= 38	.000940	.08221922
J= 39	.000943	.04000000
J= 40	.000945	.06148170
J= 41	.000948	.03768289
J= 42	.000951	.05585696
J= 43	.000956	.05118594
J= 44	.000960	.04312772
J= 45	.000966	.04604346
J= 46	.000971	.04242641
J= 47	.000976	.04024922
J= 48	.000979	.03376389
J= 49	.000982	.03898718

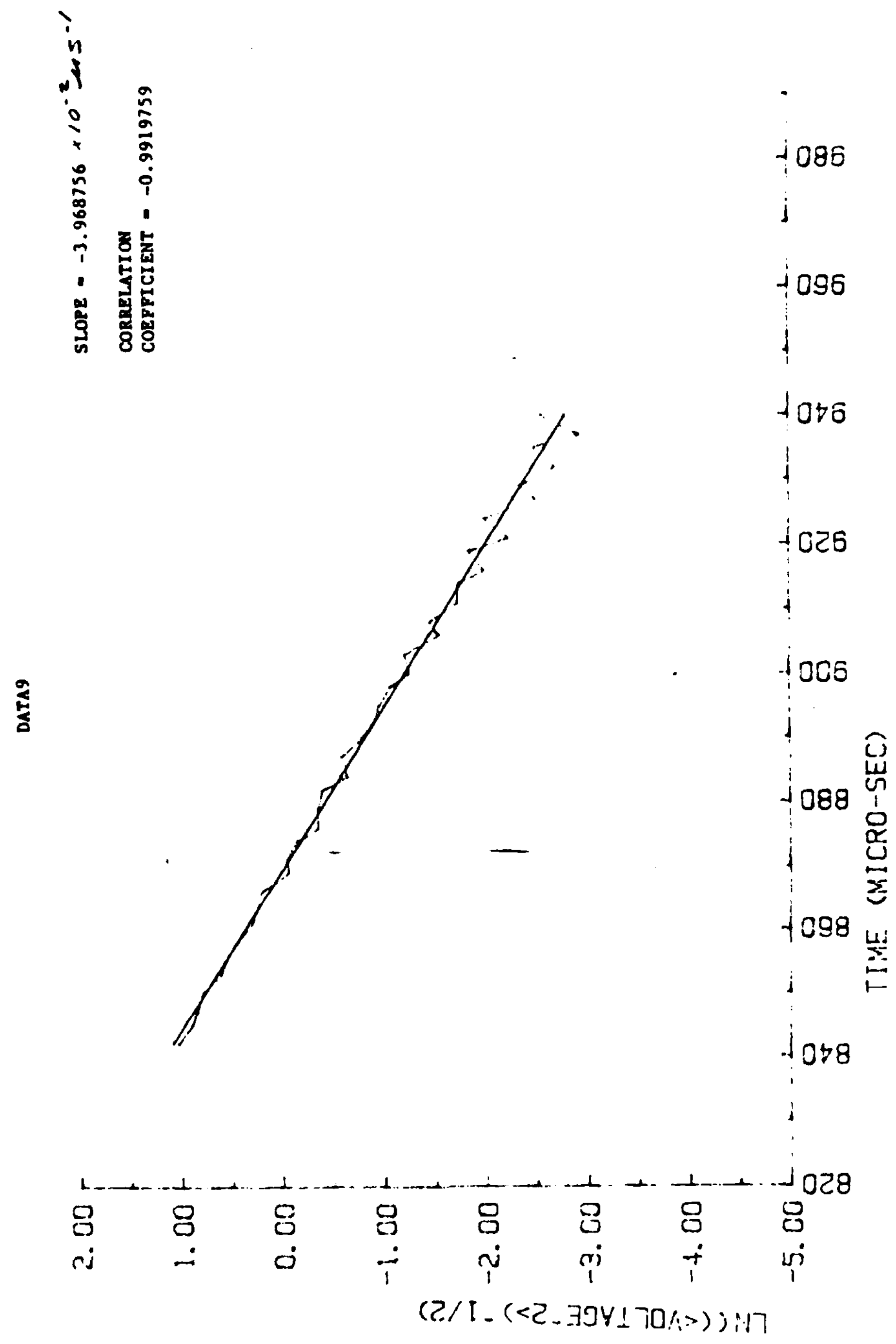

DATA8
SLOPE = -3.962827 x10^-2 μs^-1
CORRELATION
COEFFICIENT = -0.9876335
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
LN((<VOLTAGE^2>)^1/2)
820
840
860
880
900
920
940
960
980
TIME (MICRO-SEC)

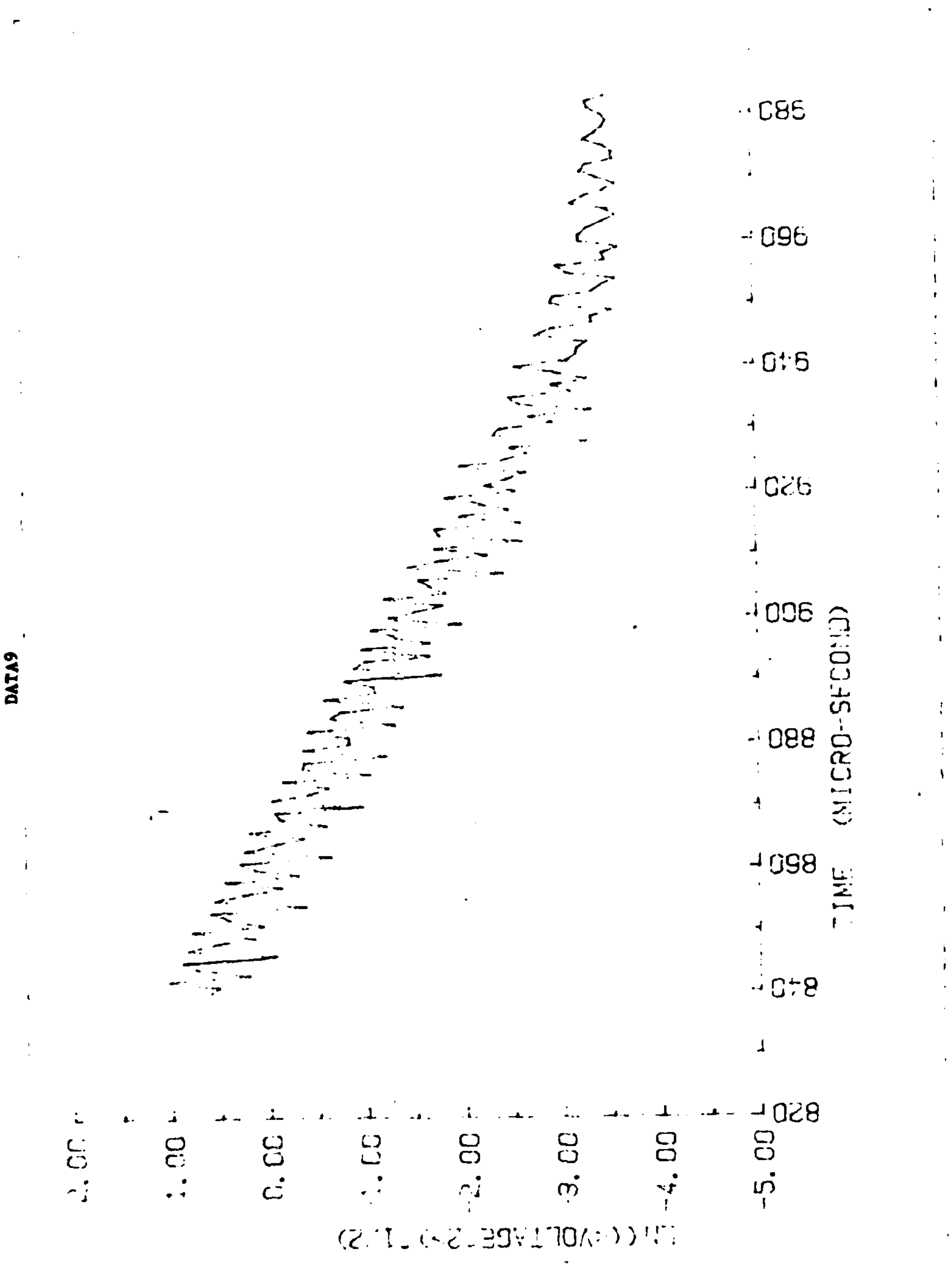

DATA8
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
820
840
860
880
900
920
940
960
980
TIME (MICRO-SECOND)

DATA9

LOCAL MAXIMA

	TIME (SEC.)	VOLT
J= 1	.000842	2.79044369
J= 2	.000845	2.42803954
J= 3	.000847	2.32221102
J= 4	.000850	2.21119696
J= 5	.000853	1.82984371
J= 6	.000855	1.74683943
J= 7	.000858	1.56490511
J= 8	.000861	1.34148574
J= 9	.000863	1.27793897
J= 10	.000866	1.22861223
J= 11	.000869	.93245053
J= 12	.000871	.95596653
J= 13	.000874	.85806760
J= 14	.000876	.69895350
J= 15	.000879	.70414203
J= 16	.000882	.66741891
J= 17	.000884	.52178923
J= 18	.000887	.55760918
J= 19	.000890	.45095454
J= 20	.000892	.41226205
J= 21	.000895	.37968408
J= 22	.000898	.34137370
J= 23	.000900	.28326666
J= 24	.000903	.29686361
J= 25	.000906	.21143320
J= 26	.000908	.23397436
J= 27	.000911	.17674841
J= 28	.000914	.17593180
J= 29	.000916	.13588230
J= 30	.000919	.15882065
J= 31	.000921	.10605659
J= 32	.000924	.13644046
J= 33	.000927	.08153527
J= 34	.000929	.09528903
J= 35	.000932	.06729042
J= 36	.000935	.08275264
J= 37	.000937	.05276362
J= 38	.000940	.07694154
J= 39	.000945	.06216108
J= 40	.000948	.03544009
J= 41	.000950	.05351635
J= 42	.000956	.05019960
J= 43	.000958	.03136877
J= 44	.000960	.03969887
J= 45	.000966	.04270831
J= 46	.000971	.03878144
J= 47	.000976	.03720215
J= 48	.000982	.03644173

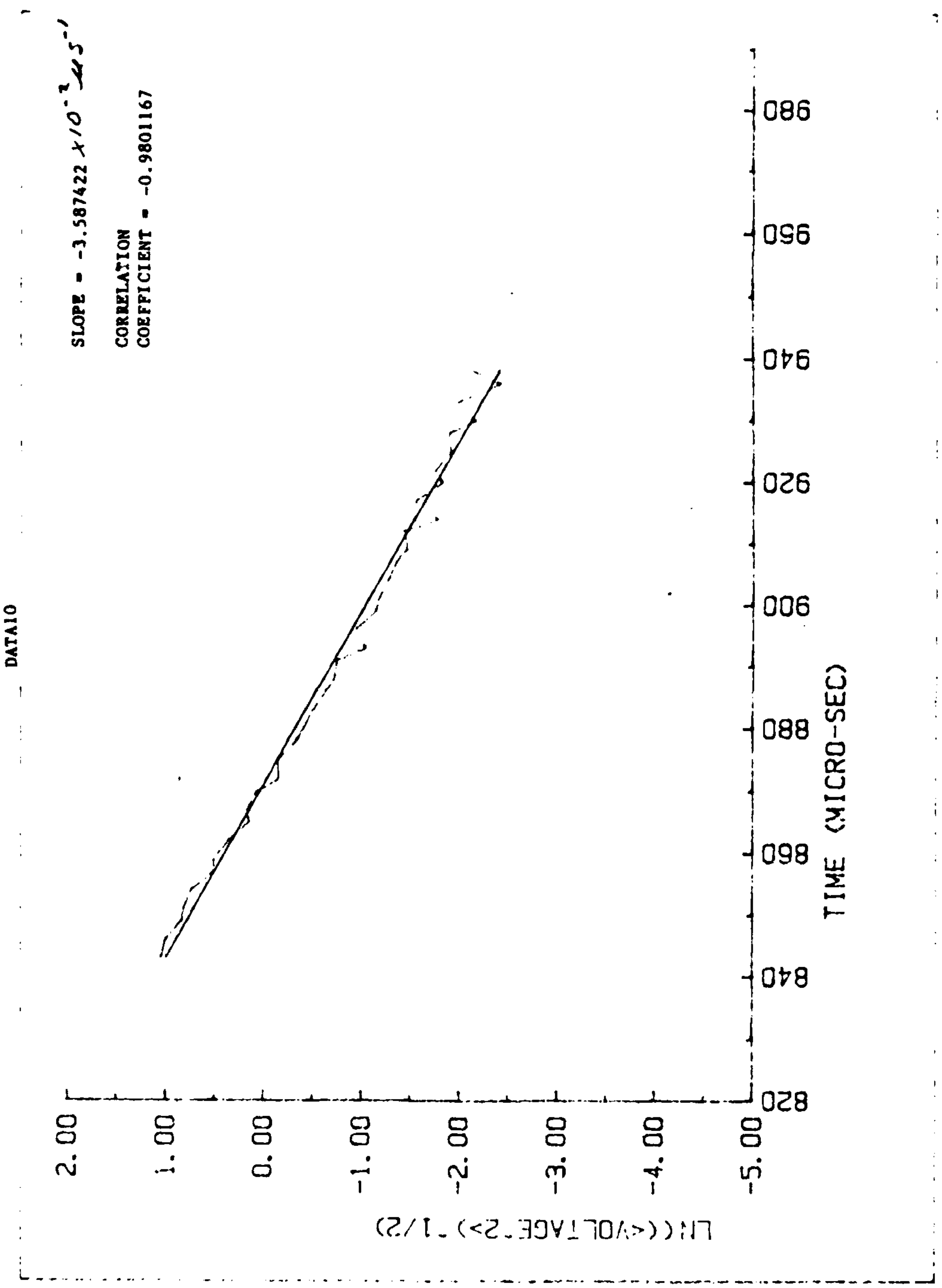

DATA9
SLOPE = -3.968756 ×10^-2 μs^-1
CORRELATION
COEFFICIENT = -0.9919759
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
LN((<VOLTAGE^2>)^1/2)
820
840
860
880
900
920
940
960
980
TIME (MICRO-SEC)

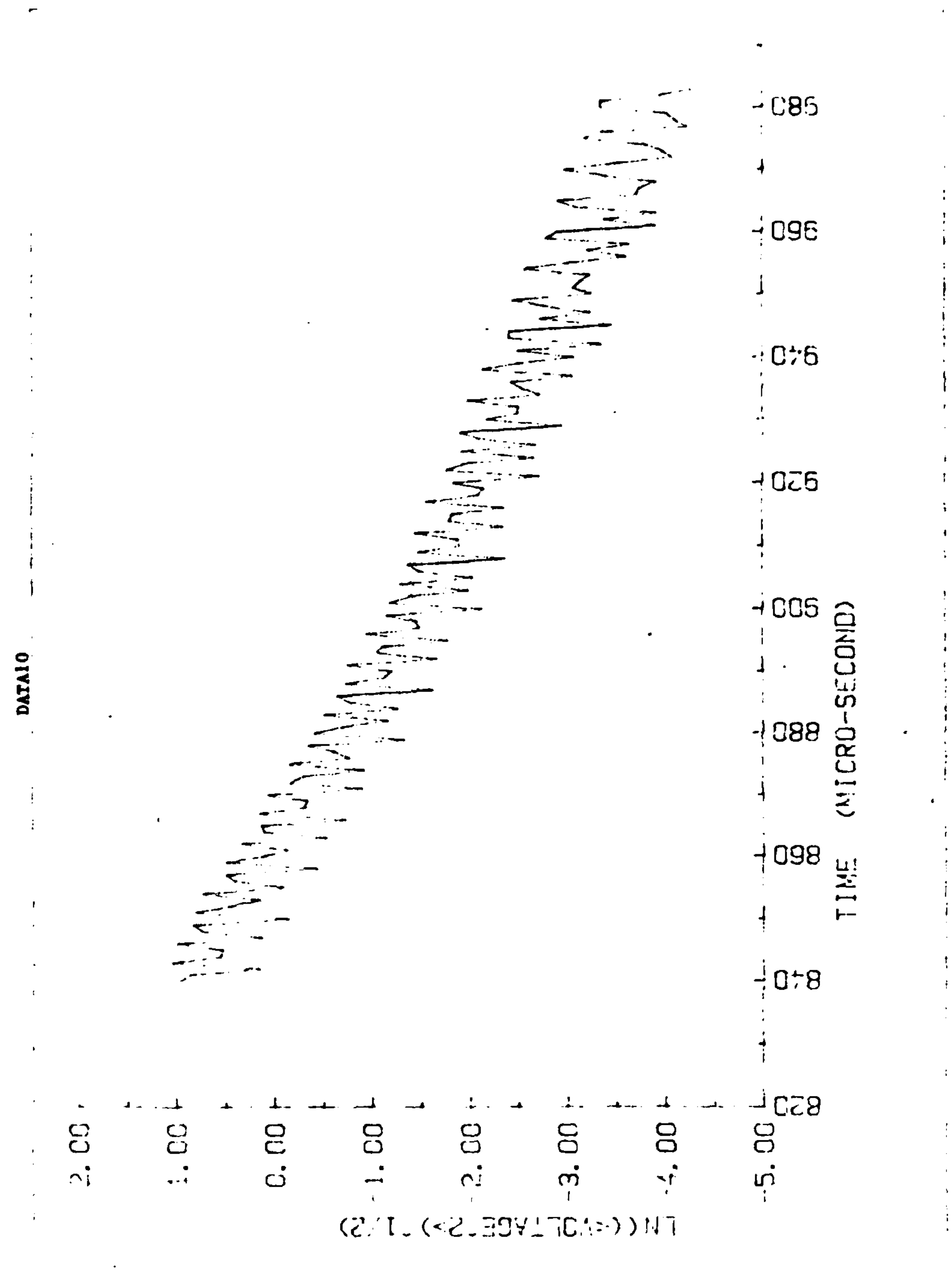

DATA9
TIME (MICRO-SECOND)
820
840
860
880
900
920
940
960
980
-5.00
-4.00
-3.00
-2.00
0.00
1.00

DATA10

LOCAL MAXIMA

		TIME (SEC.)	VOLT
J=	1	.000843	2.82483256
J=	2	.000846	2.68796959
J=	3	.000849	2.28436074
J=	4	.000851	2.22633522
J=	5	.000854	2.06975953
J=	6	.000857	1.64075790
J=	7	.000859	1.63980578
J=	8	.000862	1.41303574
J=	9	.000865	1.14007171
J=	10	.000867	1.16729088
J=	11	.000870	1.05813799
J=	12	.000872	.84032702
J=	13	.000875	.84959049
J=	14	.000878	.70170400
J=	15	.000880	.65438368
J=	16	.000883	.59486385
J=	17	.000886	.52219776
J=	18	.000888	.48041388
J=	19	.000891	.46750668
J=	20	.000893	.34809266
J=	21	.000896	.38650097
J=	22	.000899	.31211697
J=	23	.000901	.30389472
J=	24	.000904	.27546415
J=	25	.000907	.25276768
J=	26	.000909	.22705066
J=	27	.000912	.23514464
J=	28	.000914	.16651727
J=	29	.000917	.20900359
J=	30	.000920	.15851498
J=	31	.000922	.17102047
J=	32	.000925	.14651109
J=	33	.000928	.14893119
J=	34	.000930	.11303539
J=	35	.000933	.13704379
J=	36	.000936	.08780945
J=	37	.000938	.11675616
J=	38	.000941	.08147085
J=	39	.000943	.08969392
J=	40	.000946	.06491148
J=	41	.000949	.08607845
J=	42	.000951	.04629255
J=	43	.000954	.07623975
J=	44	.000957	.03974292
J=	45	.000959	.06088514
J=	46	.000962	.03406611
J=	47	.000965	.05410638
J=	48	.000970	.05094605
J=	49	.000975	.04145479
J=	50	.000981	.03519943

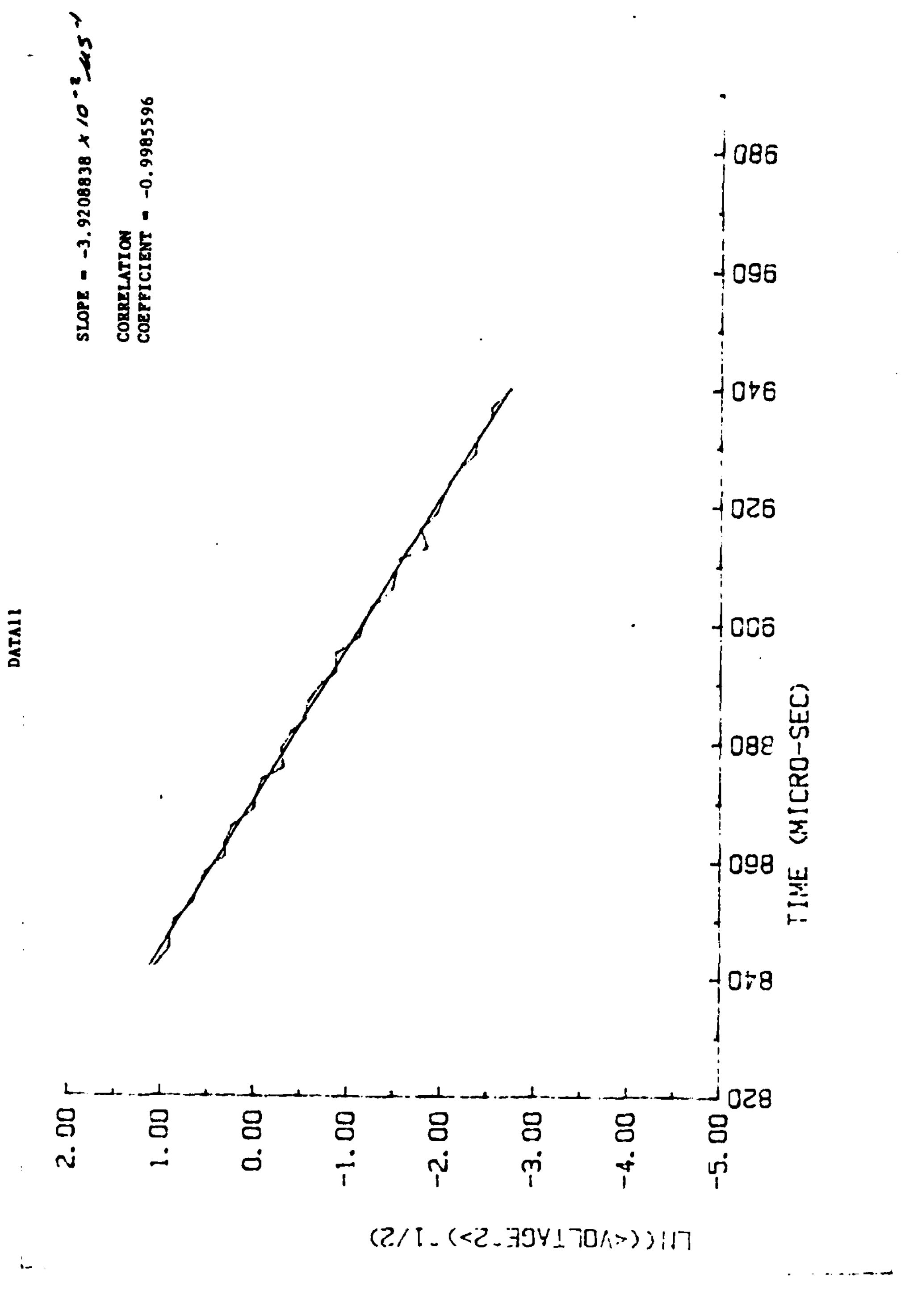

DATA10
SLOPE = -3.587422 x10^-2 µs^-1
CORRELATION
COEFFICIENT = -0.9801167
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
LN((<VOLTAGE.2>).1/2)
820
840
860
880
900
920
940
960
980
TIME (MICRO-SEC)


DATA10
TIME (MICRO-SECOND)
820
840
860
880
900
920
940
960
980
-5.00
-4.00
-3.00
-2.00
-1.00
0.00
1.00
2.00

DATA11

LOCAL MAXIMA

		TIME (SEC.)	VOLT
J=	1	.000842	2.86878511
J=	2	.000845	2.45918360
J=	3	.000847	2.46472879
J=	4	.000850	2.30432289
J=	5	.000853	1.90630533
J=	6	.000855	1.82231062
J=	7	.000858	1.67886867
J=	8	.000861	1.35363215
J=	9	.000863	1.35458333
J=	10	.000866	1.25505697
J=	11	.000869	.98838859
J=	12	.000871	.97666371
J=	13	.000874	.90785902
J=	14	.000876	.71765730
J=	15	.000879	.74785025
J=	16	.000882	.66050889
J=	17	.000884	.57047349
J=	18	.000887	.55370028
J=	19	.000890	.48289129
J=	20	.000892	.41059956
J=	21	.000895	.41605769
J=	22	.000898	.32057448
J=	23	.000900	.30780513
J=	24	.000903	.28227646
J=	25	.000906	.22460632
J=	26	.000908	.21927152
J=	27	.000911	.20830747
J=	28	.000913	.15592306
J=	29	.000916	.16838052
J=	30	.000919	.13988567
J=	31	.000921	.13389548
J=	32	.000924	.12325583
J=	33	.000927	.10710742
J=	34	.000929	.09277931
J=	35	.000932	.09138928
J=	36	.000935	.07863841
J=	37	.000937	.07858753
J=	38	.000940	.06437391
J=	39	.000942	.06794115
J=	40	.000945	.04923413
J=	41	.000948	.05761944
J=	42	.000950	.04489989
J=	43	.000953	.05374012
J=	44	.000956	.03979950
J=	45	.000958	.04543127
J=	46	.000961	.03521363
J=	47	.000963	.04354308
J=	48	.000966	.03274141
J=	49	.000969	.04445222
J=	50	.000972	.03762978
J=	51	.000975	.04049691
J=	52	.000979	.03929377
J=	53	.000982	.03784178


DATA11
SLOPE = -3.9208838 x 10^-2 µs^-1
CORRELATION
COEFFICIENT = -0.9985596
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
820
840
860
880
900
920
940
960
980
TIME (MICRO-SEC)

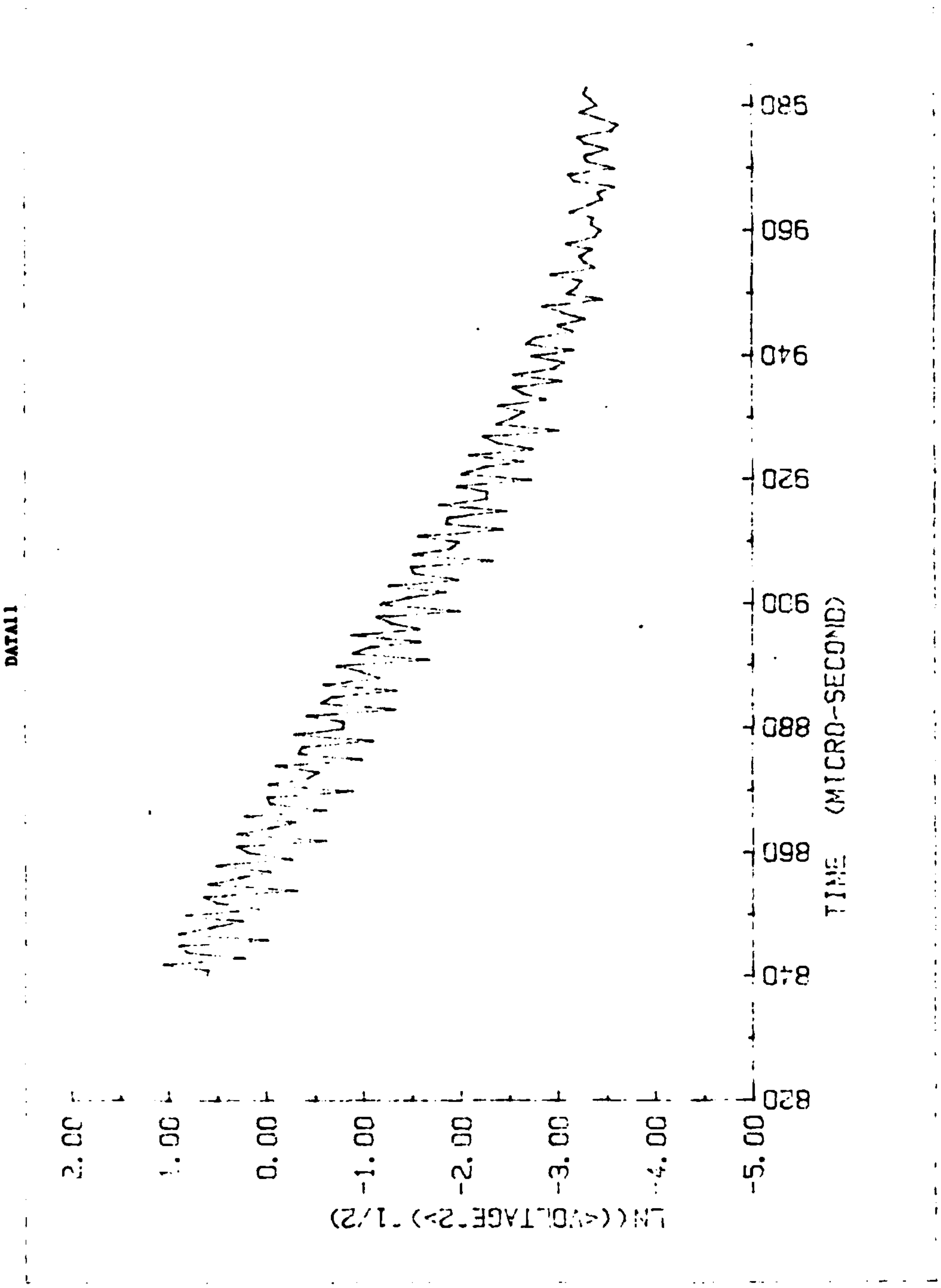

DATA11
TIME (MICRO-SECOND)
820
840
860
880
900
920
940
960
980
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00

TABLE 2

AGGREGATE REFLECTION

FREQUENCY: 185kHz

DATA SET	SAMPLE TIME (μs)	NUMBER OF SAMPLES IN DATA SET	SLOPE ($x10^{-2}$)	CORRELATION COEFFICIENT
DATA1	822-940	100	-3.2230	-0.9355
DATA2	816-940	100	-3.1460	-0.9657
DATA5	852-940	100	-3.9916	-0.9919
DATA12	840-940	50	-2.2354	-0.9284
DATA13	840-940	100	-2.2395	-0.9261
DATA14	840-940	50	-2.5359	-0.8356
DATA15*	540-580	50	-4.4800	-0.9679
DATA16**	760-840	50	-3.3925	-0.9163
DATA17***	1000-1090	50	-3.9117	-0.9673

MEAN SLOPE = $-3.24 \times 10^{-2}\ \mu s^{-1}$
$\sigma = 0.80 \times 10^{-2}\ \mu s^{-1}$

* Distance from F-41 active face to sediment surface = 30 cm
** " " " " " " " " = 50 cm
*** " " " " " " " " = 70 cm

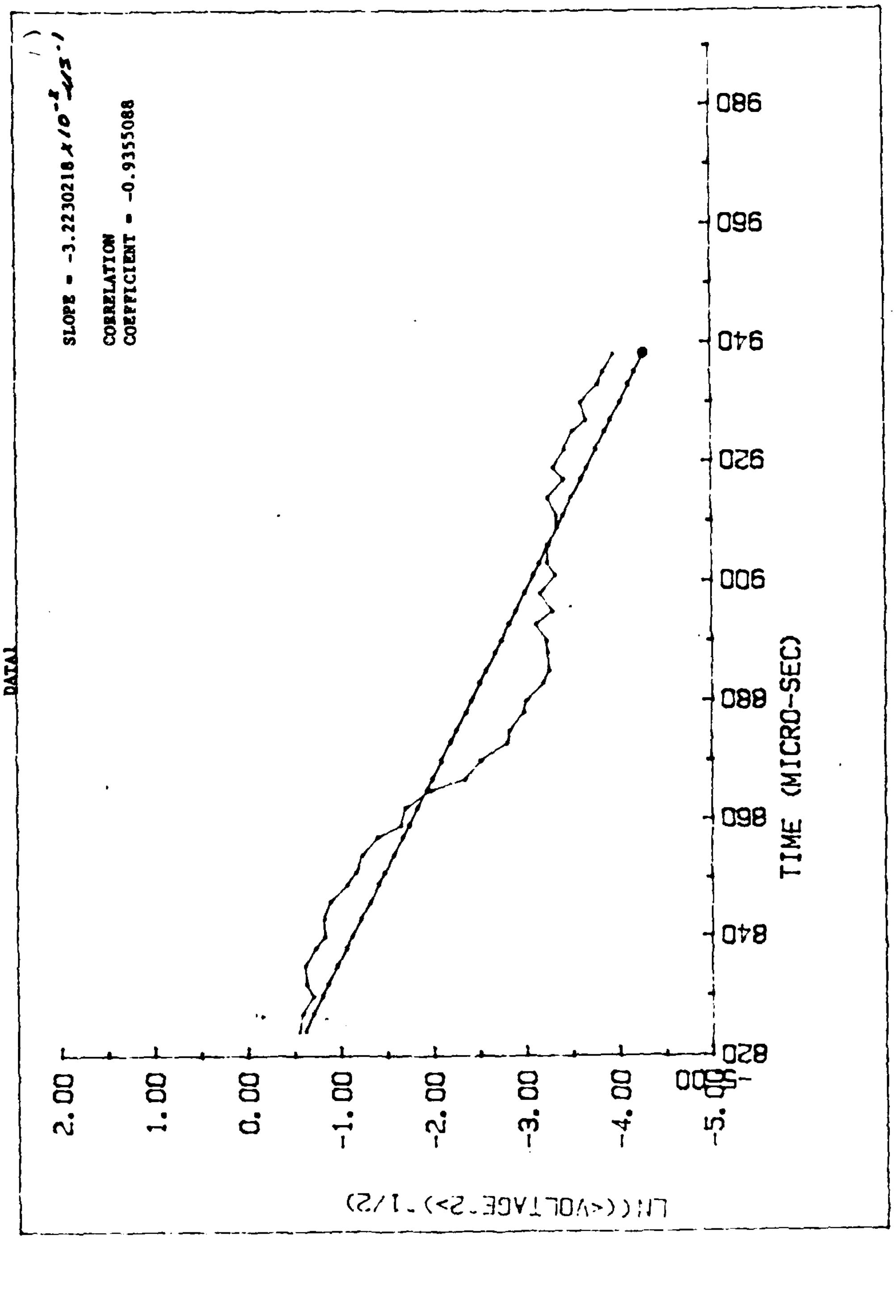
With DATA15 excluded from the selected samples;

MEAN SLOPE = $-3.08 \times 10^{-2}\ \mu s^{-1}$
$\sigma = 0.69 \times 10^{-2}\ \mu s^{-1}$

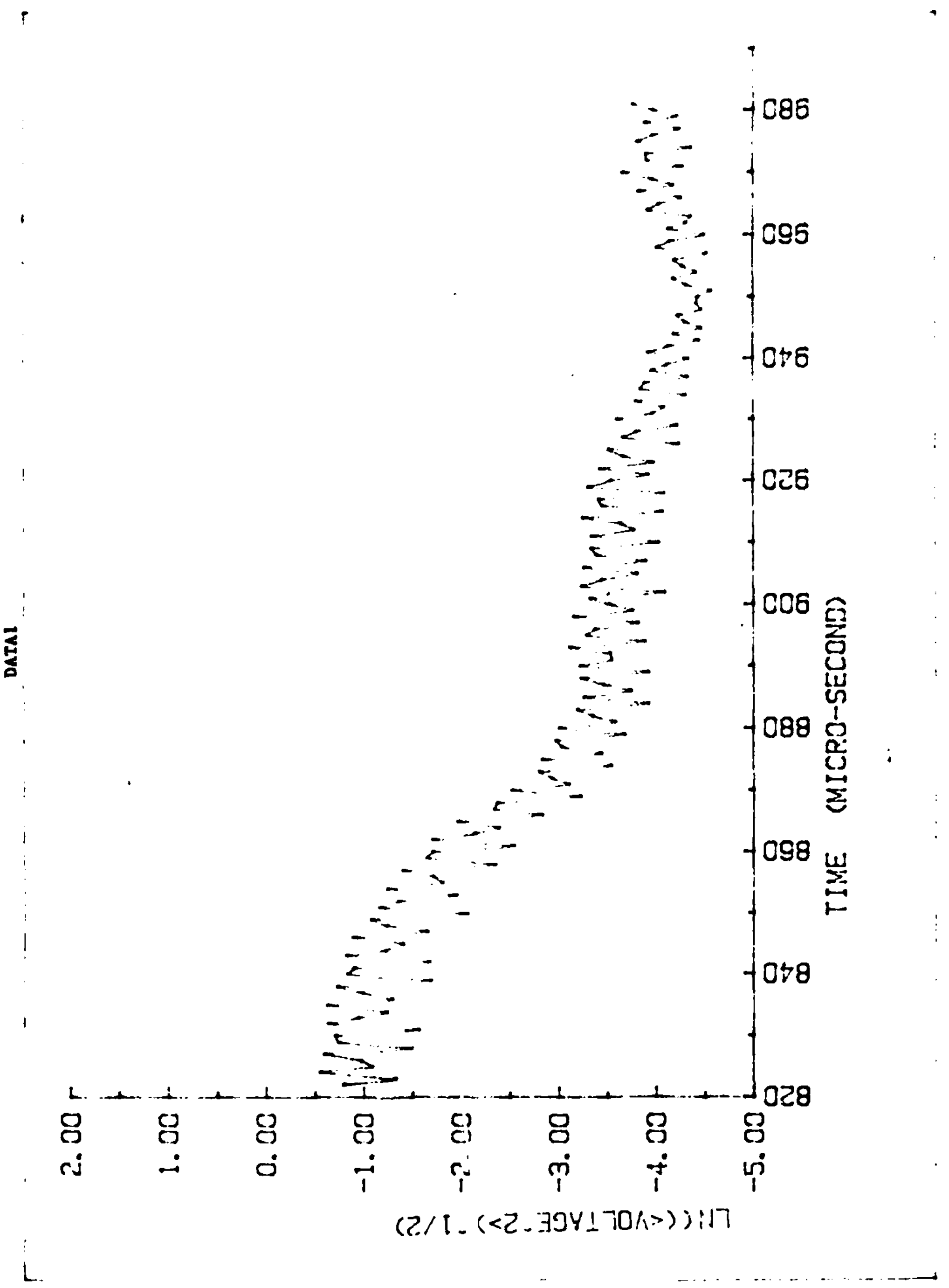
DATA1

LOCAL MAXIMA

		TIME (SEC.)	VOLT
J=	1	.000824	.57628022
J=	2	.000827	.55382207
J=	3	.000830	.49387445
J=	4	.000832	.53072987
J=	5	.000835	.53843403
J=	6	.000838	.48344567
J=	7	.000840	.43328920
J=	8	.000843	.43946235
J=	9	.000846	.41009449
J=	10	.000849	.34025304
J=	11	.000851	.31111625
J=	12	.000854	.28984644
J=	13	.000857	.24713019
J=	14	.000859	.19278288
J=	15	.000862	.18139515
J=	16	.000865	.13988116
J=	17	.000867	.09621143
J=	18	.000870	.08093312
J=	19	.000873	.06076652
J=	20	.000875	.05901839
J=	21	.000878	.05104087
J=	22	.000880	.04949232
J=	23	.000883	.04113952
J=	24	.000885	.03846089
J=	25	.000888	.03946568
J=	26	.000890	.03987079
J=	27	.000893	.04427302
J=	28	.000895	.03733323
J=	29	.000898	.04256642
J=	30	.000901	.03588398
J=	31	.000903	.03924589
J=	32	.000906	.03847207
J=	33	.000909	.03540523
J=	34	.000911	.03558834
J=	35	.000914	.03876003
J=	36	.000917	.03284144
J=	37	.000919	.03671294
J=	38	.000922	.03248908
J=	39	.000925	.02973298
J=	40	.000927	.02557069
J=	41	.000930	.02736933
J=	42	.000933	.02255394
J=	43	.000935	.02129906
J=	44	.000938	.01910393
J=	45	.000941	.01982347
J=	46	.000944	.01525287
J=	47	.000947	.01464582
J=	48	.000949	.01207394
J=	49	.000953	.01541623
J=	50	.000956	.01516905
J=	51	.000958	.01808922
J=	52	.000961	.01612328
J=	53	.000964	.01986001
J=	54	.000967	.02189383
J=	55	.000970	.02557577
J=	56	.000973	.02016284
J=	57	.000975	.02220113
J=	58	.000978	.02042964



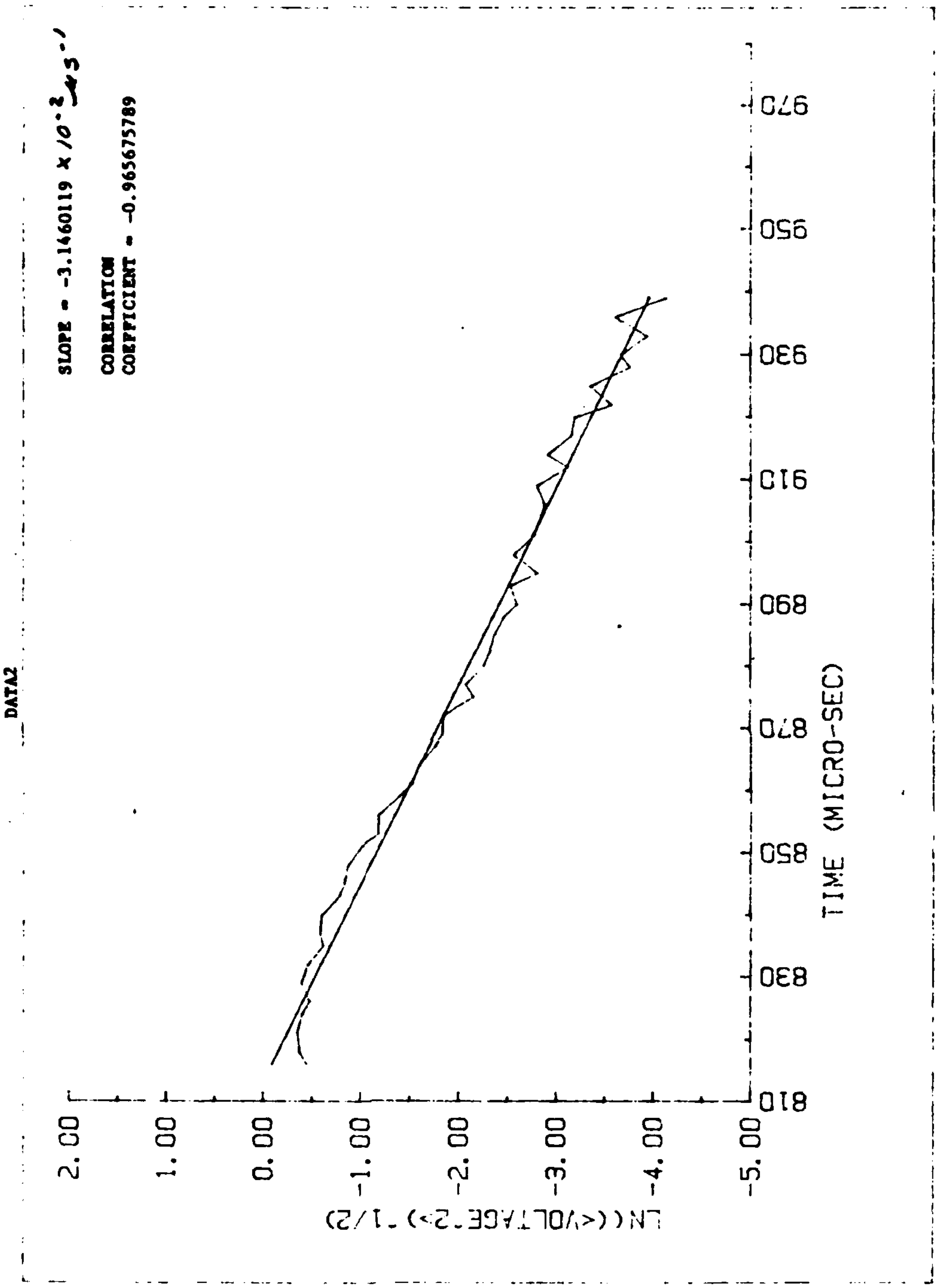
DATA1
SLOPE = -3.2230218 x10^-2 µs^-1
CORRELATION
COEFFICIENT = -0.9355088
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
820
840
860
880
900
920
940
960
980
TIME (MICRO-SEC)
LN((<VOLTAGE^2>)^1/2)

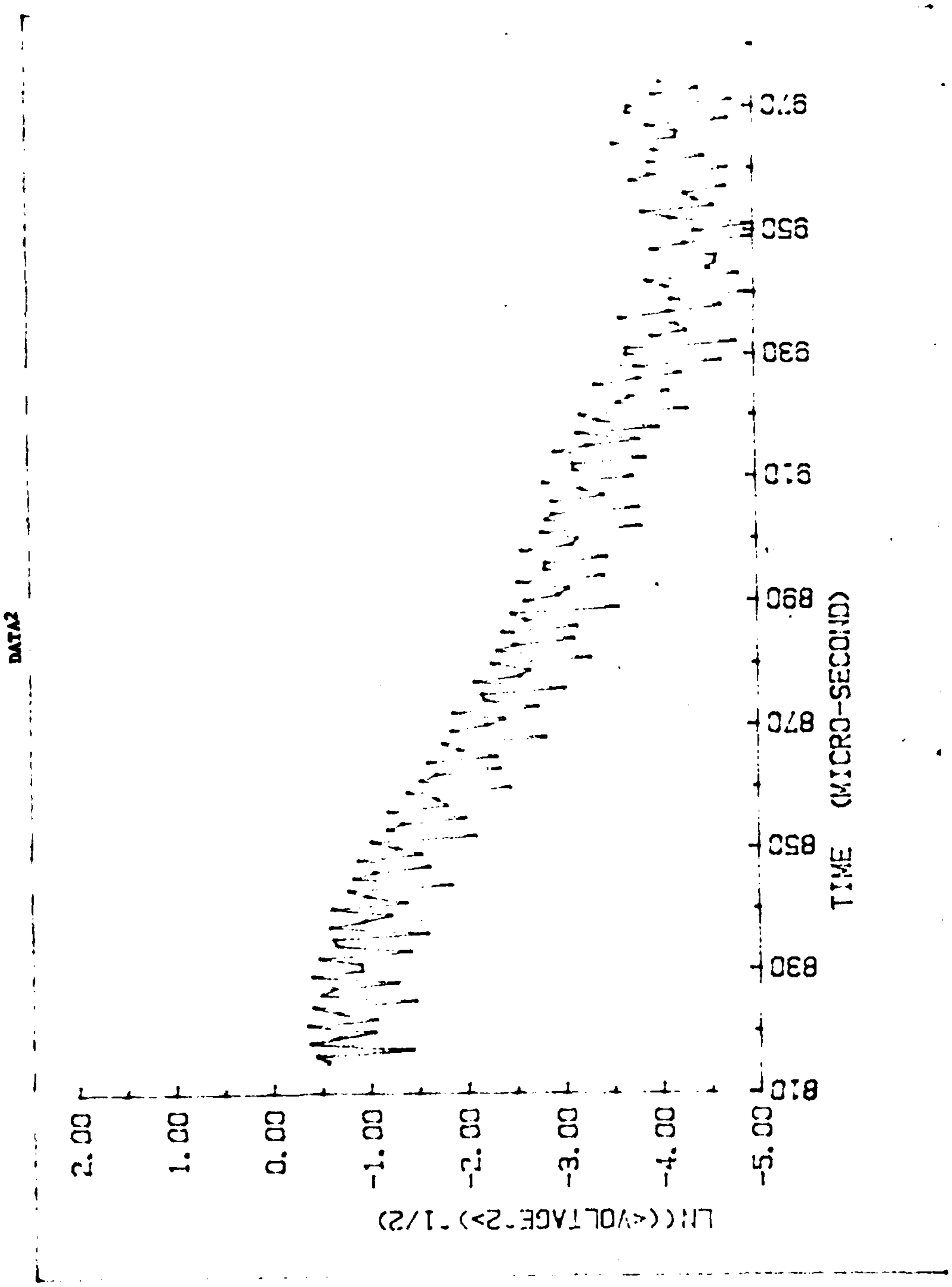

DATA1
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
LN((<VOLTAGE^2>)^1/2)
820
840
860
880
900
920
940
960
980
TIME (MICRO-SECOND)

DATA2

LOCAL MAXIMA

	TIME (SEC.)	VOLT
J= 0	.000816	.63647171
J= 1	.000818	.68670934
J= 2	.000821	.70203319
J= 3	.000824	.66687636
J= 4	.000826	.61608006
J= 5	.000829	.67264386
J= 6	.000832	.62724075
J= 7	.000835	.53890856
J= 8	.000837	.55637189
J= 9	.000840	.54457282
J= 10	.000843	.45660950
J= 11	.000845	.43432757
J= 12	.000848	.41456570
J= 13	.000851	.36207397
J= 14	.000853	.30559234
J= 15	.000856	.30398053
J= 16	.000859	.24790143
J= 17	.000861	.21753786
J= 18	.000864	.20195197
J= 19	.000867	.17177241
J= 20	.000869	.15779354
J= 21	.000872	.15518454
J= 22	.000875	.11536187
J= 23	.000877	.12406160
J= 24	.000880	.10410226
J= 25	.000882	.09816313
J= 26	.000885	.09290533
J= 27	.000888	.08415153
J= 28	.000890	.07392834
J= 29	.000893	.07903265
J= 30	.000895	.05997753
J= 31	.000898	.07615405
J= 32	.000901	.06199226
J= 33	.000903	.05896643
J= 34	.000906	.05559856
J= 35	.000909	.06012121
J= 36	.000912	.04392175
J= 37	.000914	.05391549
J= 38	.000917	.04228664
J= 39	.000920	.04068857
J= 40	.000922	.02782876
J= 41	.000925	.03483906
J= 42	.000928	.02314044
J= 43	.000930	.02542361
J= 44	.000933	.01934425
J= 45	.000936	.02685070
J= 46	.000939	.01602248
J= 47	.000942	.02043233
J= 48	.000944	.01098180
J= 49	.000947	.01932977
J= 50	.000950	.01244990
J= 51	.000953	.02127346
J= 52	.000956	.01371568
J= 53	.000958	.02376300
J= 54	.000961	.01977372
J= 55	.000964	.02856011
J= 56	.000967	.02011765
J= 57	.000969	.02471194
J= 58	.000972	.01903365

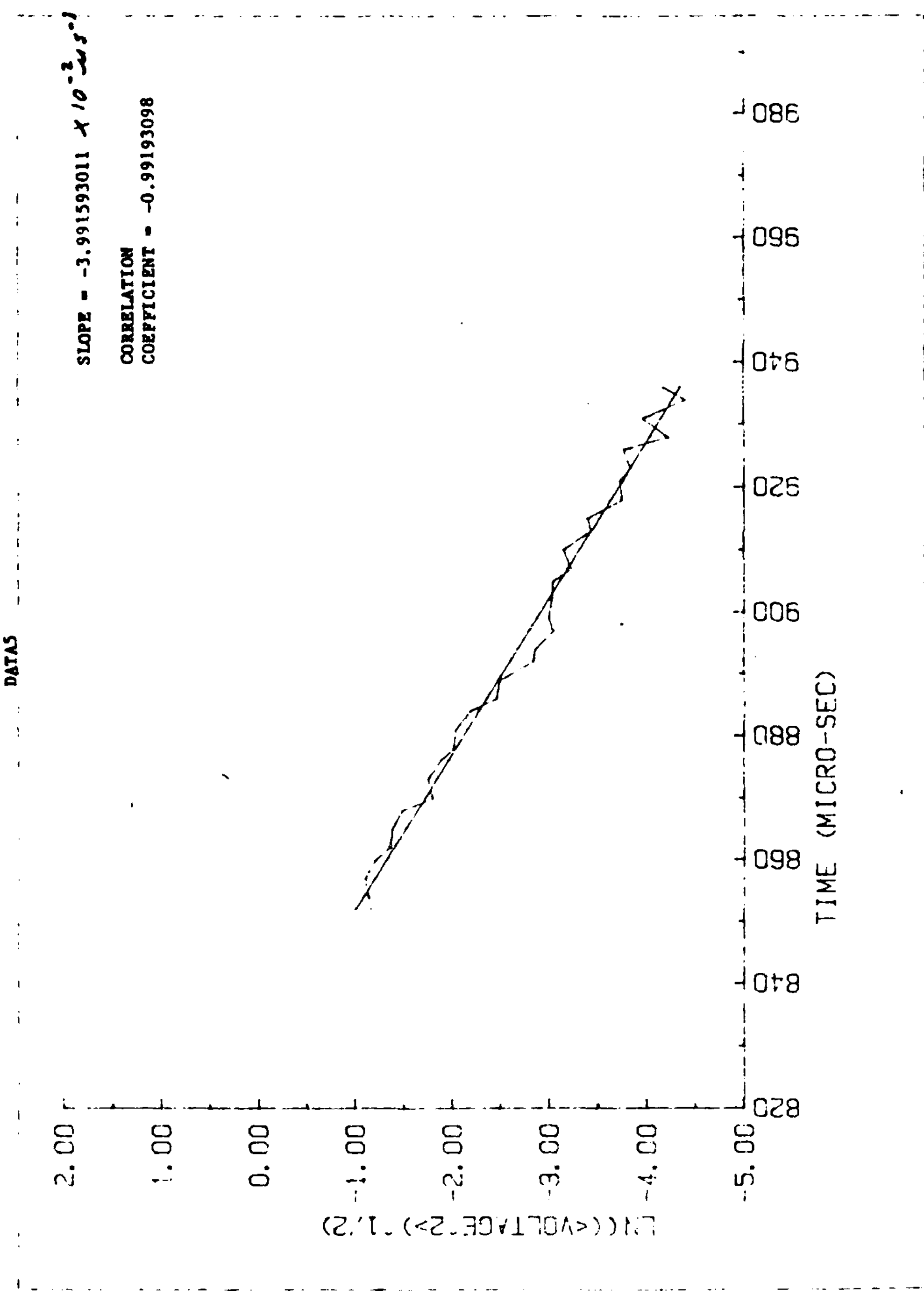

DATA2
SLOPE = -3.1460119 x 10^-3 μs^-1
CORRELATION COEFFICIENT = -0.965675789
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
LN((<VOLTAGE^2>)^1/2)
810
830
850
870
890
910
930
950
970
TIME (MICRO-SEC)


DATA2
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
LN((<VOLTAGE^2>)^1/2)
810
830
850
870
890
910
930
950
970
TIME (MICRO-SECOND)

DATA5

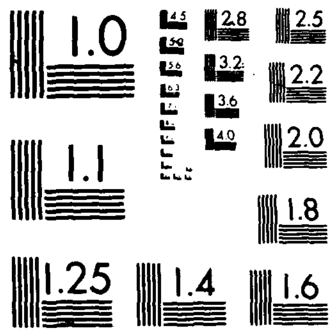
LOCAL MAXIMA

		TIME (SEC.)	VOLT
J=	0	.000852	.30892374
J=	1	.000854	.31977533
J=	2	.000857	.33199967
J=	3	.000860	.29787944
J=	4	.000862	.25730970
J=	5	.000865	.25062865
J=	6	.000868	.22680622
J=	7	.000870	.16560574
J=	8	.000873	.17395344
J=	9	.000876	.15221872
J=	10	.000878	.13277869
J=	11	.000881	.12960988
J=	12	.000884	.11217362
J=	13	.000886	.08519671
J=	14	.000889	.08202792
J=	15	.000892	.05833867
J=	16	.000894	.05723163
J=	17	.000897	.04735462
J=	18	.000899	.04970070
J=	19	.000902	.04799667
J=	20	.000905	.04755439
J=	21	.000907	.03948544
J=	22	.000910	.04260728
J=	23	.000913	.03224872
J=	24	.000915	.03359196
J=	25	.000918	.02352998
J=	26	.000921	.02405203
J=	27	.000923	.02148302
J=	28	.000926	.02309026
J=	29	.000928	.01456846
J=	30	.000931	.01894149
J=	31	.000934	.01216799
J=	32	.000936	.01524926
J=	33	.000939	.00536843
J=	34	.000941	.00569912
J=	35	.000945	.00736206
J=	36	.000948	.00413521
J=	37	.000951	.01268779
J=	38	.000954	.00887919
J=	39	.000956	.01025671
J=	40	.000959	.00398748
J=	41	.000962	.00669477

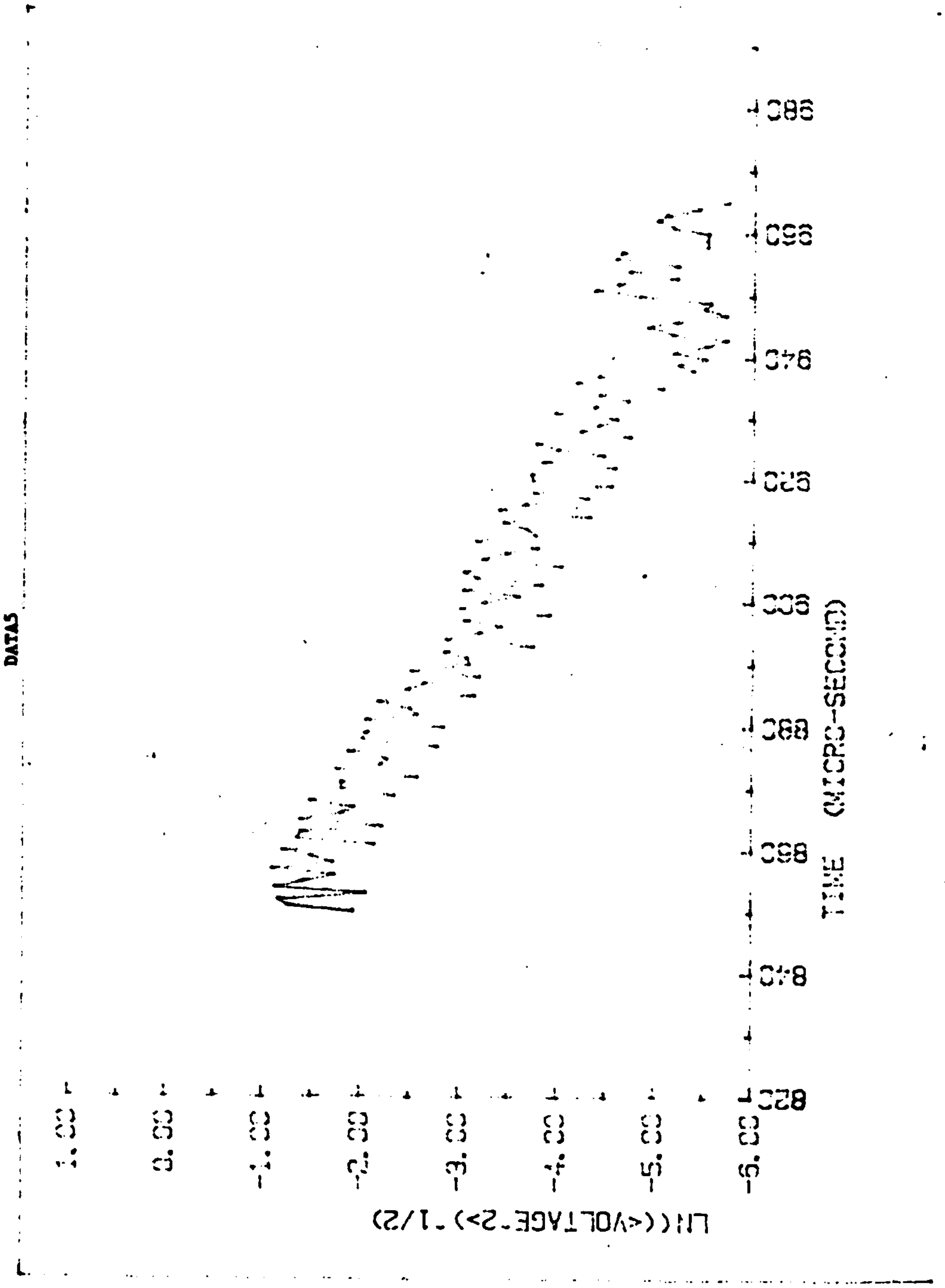

DATA5
SLOPE = -3.991593011 x 10^-2 μs^-1
CORRELATION COEFFICIENT = -0.99193098
TIME (MICRO-SEC)
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
820
840
860
880
900
920
940
960
980

AD-A175 261 PRELIMINARY STUDIES OF A TECHNIQUE FOR MEASURING THE VOLUME BACKSCATTERING FROM SEDIMENTS(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA F R DIAZ SEP 86 2/2

UNCLASSIFIED F/G 20/1 NL



ROCOPY RESOLUTION TEST CHART

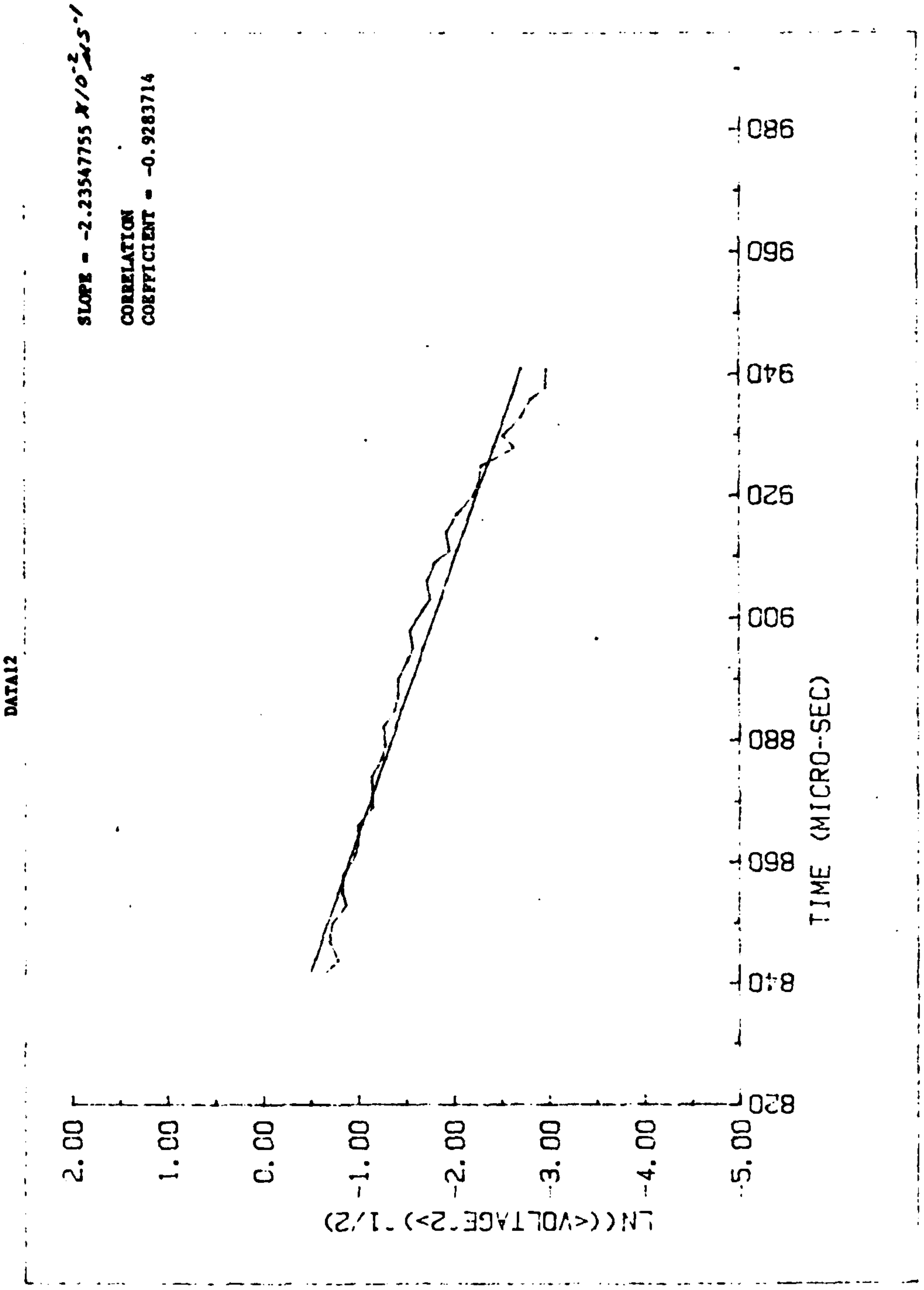


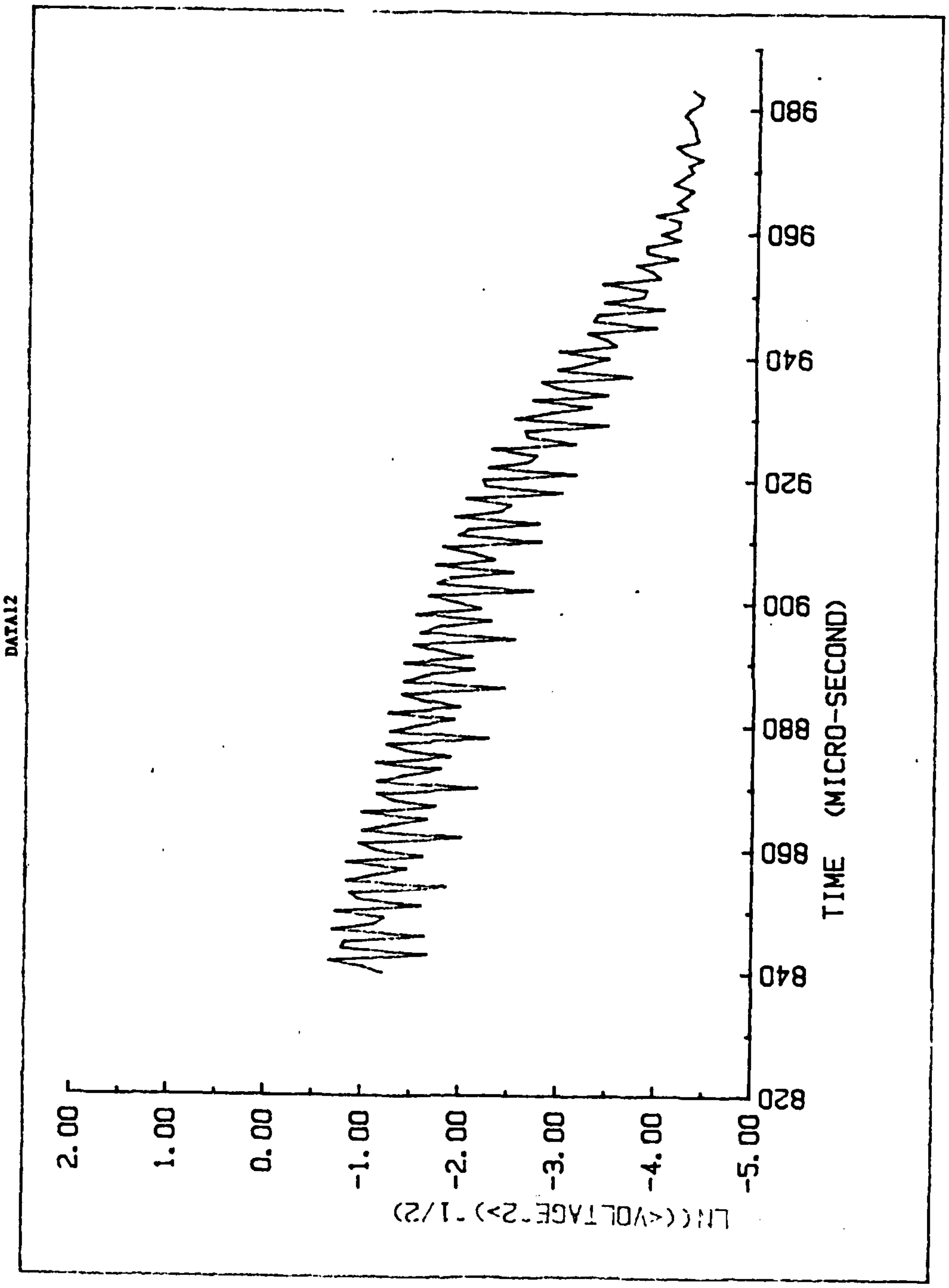
DATA5
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
LN((<VOLTAGE^2>)^1/2)
820
840
860
880
900
920
940
960
980
TIME (MICRO-SECOND)

DATA12

LOCAL MAXIMA

	TIME (SEC.)	VOLT
J= 0	.000842	.51143252
J= 1	.000844	.45515512
J= 2	.000847	.49761029
J= 3	.000850	.48393681
J= 4	.000853	.41767782
J= 5	.000855	.43380745
J= 6	.000858	.43167242
J= 7	.000861	.37847795
J= 8	.000863	.36895122
J= 9	.000866	.37085927
J= 10	.000869	.31776186
J= 11	.000871	.31723461
J= 12	.000874	.32058447
J= 13	.000877	.28823428
J= 14	.000879	.27889586
J= 15	.000882	.28351705
J= 16	.000885	.24864774
J= 17	.000887	.24120448
J= 18	.000890	.24103962
J= 19	.000893	.22059383
J= 20	.000895	.20647034
J= 21	.000898	.21414131
J= 22	.000901	.18922119
J= 23	.000903	.17416176
J= 24	.000906	.17814000
J= 25	.000909	.16489542
J= 26	.000911	.14071105
J= 27	.000914	.14640847
J= 28	.000917	.13048716
J= 29	.000920	.10982805
J= 30	.000922	.10438199
J= 31	.000925	.10111152
J= 32	.000928	.07178203
J= 33	.000930	.08052602
J= 34	.000933	.06700940
J= 35	.000936	.06069432
J= 36	.000938	.05167088
J= 37	.000941	.05097960
J= 38	.000944	.03818796
J= 39	.000946	.03599167
J= 40	.000949	.03224035
J= 41	.000952	.03305874
J= 42	.000955	.02339573
J= 43	.000958	.02101047
J= 44	.000960	.01809420
J= 45	.000963	.01920260
J= 46	.000965	.01550806
J= 47	.000968	.01601062
J= 48	.000971	.01384919
J= 49	.000974	.01571305

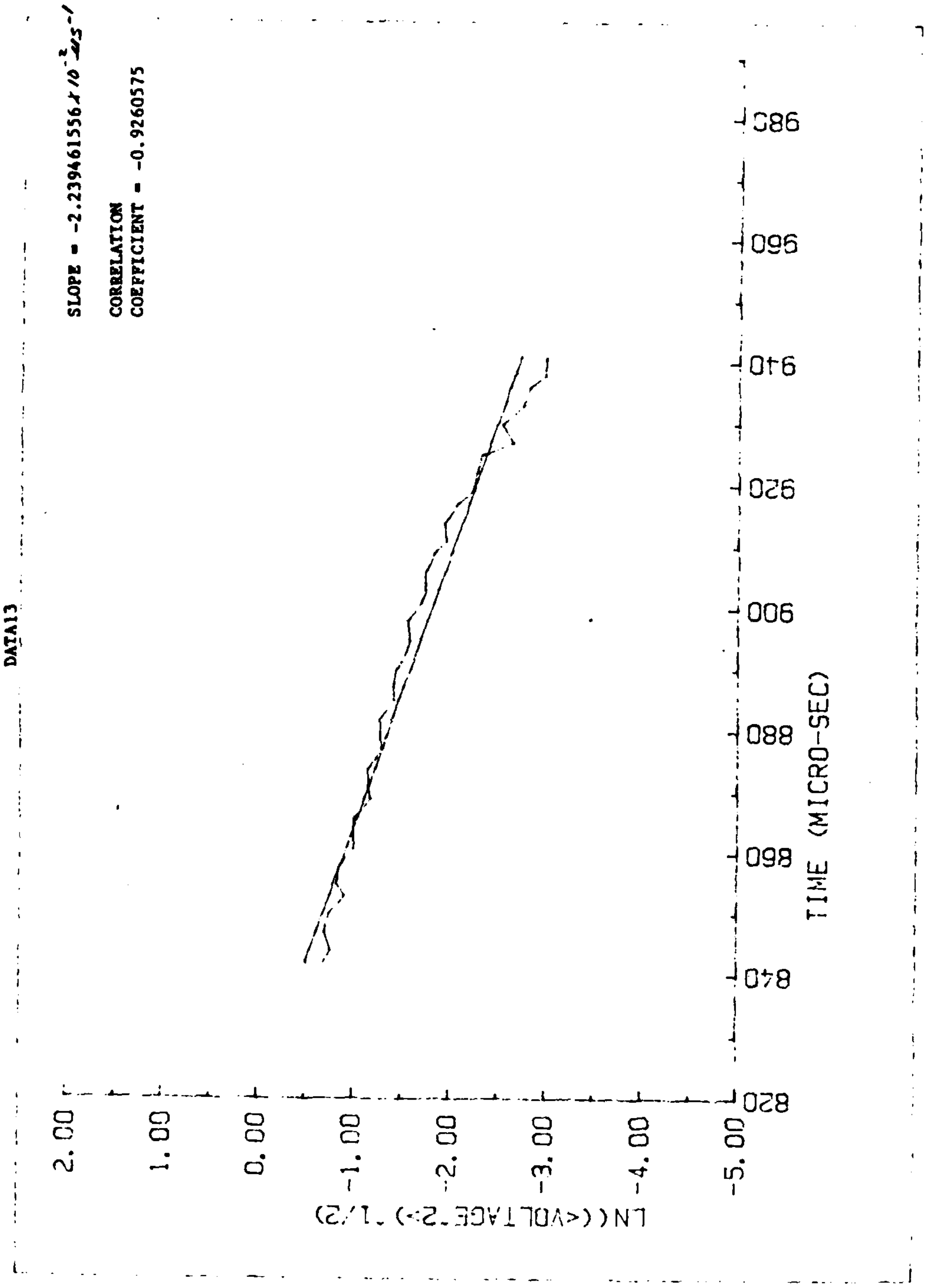

DATA12
SLOPE = -2.23547755 x10^-2 µs^-1
CORRELATION
COEFFICIENT = -0.9283714
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
LN((<VOLTAGE^2>)^1/2)
820
840
860
880
900
920
940
960
980
TIME (MICRO-SEC)

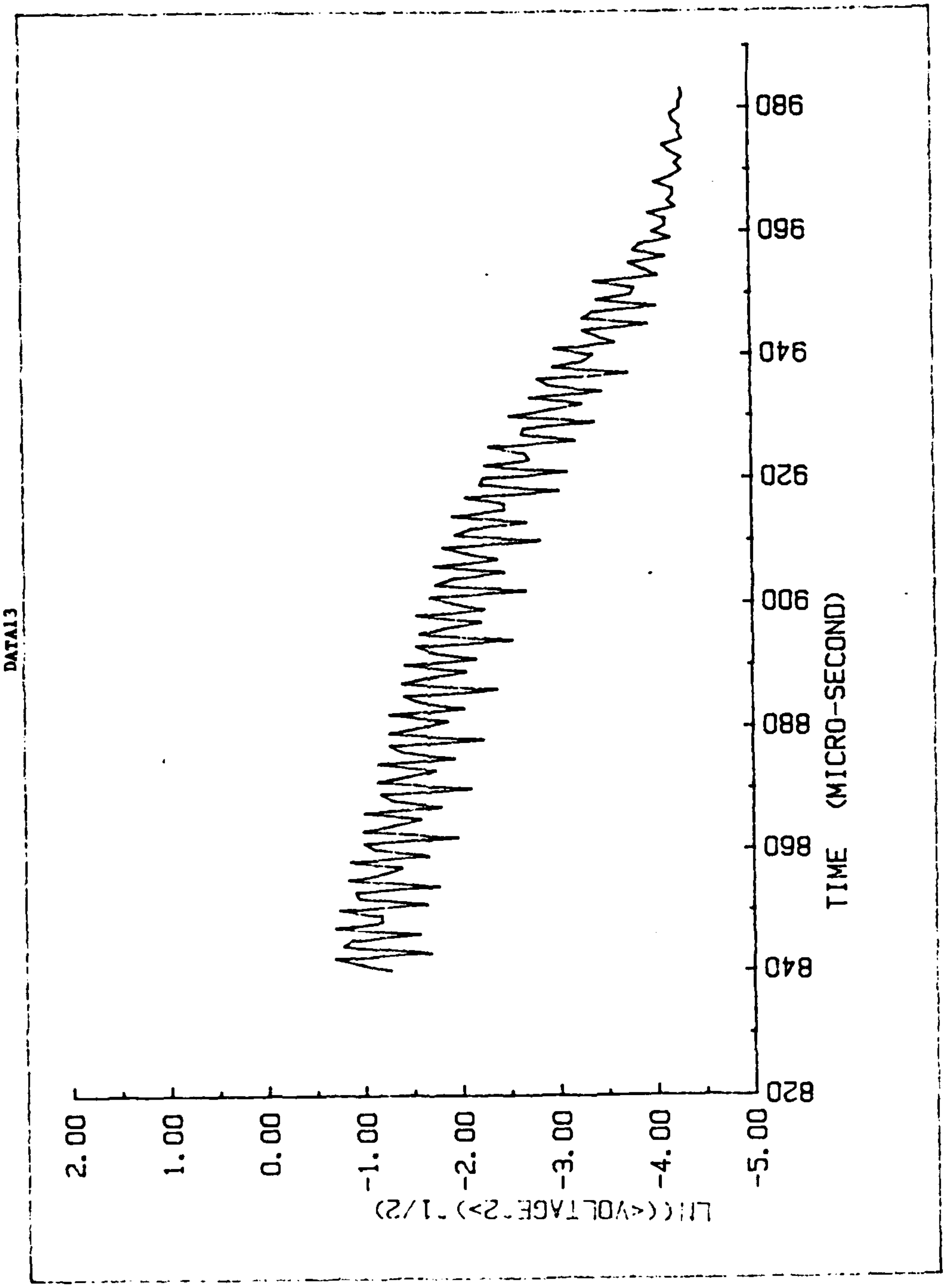

DATA12
TIME (MICRO-SECOND)
820
840
860
880
900
920
940
960
980
LN((<VOLTAGE^2>)^1/2)
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00

DATA13

LOCAL MAXIMA

	TIME (SEC.)	VOLT
J= 0	.000842	.49913686
J= 1	.000844	.46259928
J= 2	.000847	.49610785
J= 3	.000850	.47599414
J= 4	.000853	.40373306
J= 5	.000855	.43505798
J= 6	.000858	.42462047
J= 7	.000861	.36693566
J= 8	.000863	.36960317
J= 9	.000866	.36574759
J= 10	.000869	.30842876
J= 11	.000871	.31796839
J= 12	.000874	.31615850
J= 13	.000877	.27968643
J= 14	.000879	.28068746
J= 15	.000882	.28086288
J= 16	.000885	.24147640
J= 17	.000887	.24417576
J= 18	.000890	.23726156
J= 19	.000893	.21405798
J= 20	.000895	.20650182
J= 21	.000898	.21123269
J= 22	.000901	.18393023
J= 23	.000903	.17552538
J= 24	.000906	.17617869
J= 25	.000909	.16110012
J= 26	.000911	.14185838
J= 27	.000914	.14552567
J= 28	.000917	.12739878
J= 29	.000919	.10946625
J= 30	.000922	.10387396
J= 31	.000925	.09897863
J= 32	.000927	.07104794
J= 33	.000930	.08049981
J= 34	.000933	.06514699
J= 35	.000936	.05969003
J= 36	.000938	.05119512
J= 37	.000941	.05037321
J= 38	.000944	.03716396
J= 39	.000946	.03737245
J= 40	.000949	.03230666
J= 41	.000952	.03342813
J= 42	.000955	.02316635
J= 43	.000957	.02210927
J= 44	.000960	.01818516
J= 45	.000963	.01895706
J= 46	.000965	.01550000
J= 47	.000968	.01775303
J= 48	.000971	.01434922
J= 49	.000974	.01623114
J= 50	.000976	.01383944

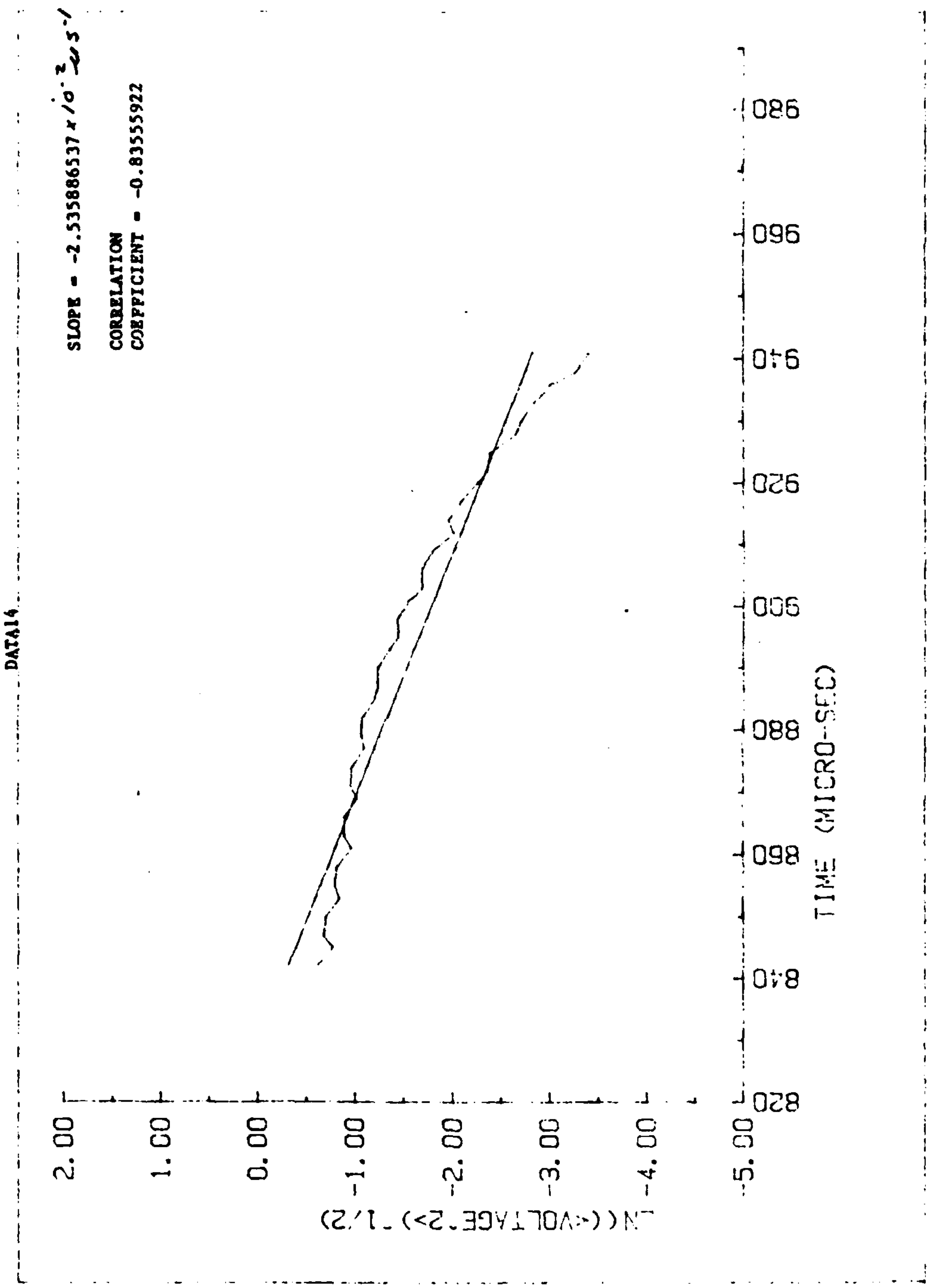

DATA13
SLOPE = -2.239461556 x 10^-2 μs^-1
CORRELATION COEFFICIENT = -0.9260575
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
LN((<VOLTAGE^2>)^1/2)
820
840
860
880
900
920
940
960
980
TIME (MICRO-SEC)


DATA13
TIME (MICRO-SECOND)
820
840
860
880
900
920
940
960
980
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
LN((<VOLTAGE^2>)^1/2)

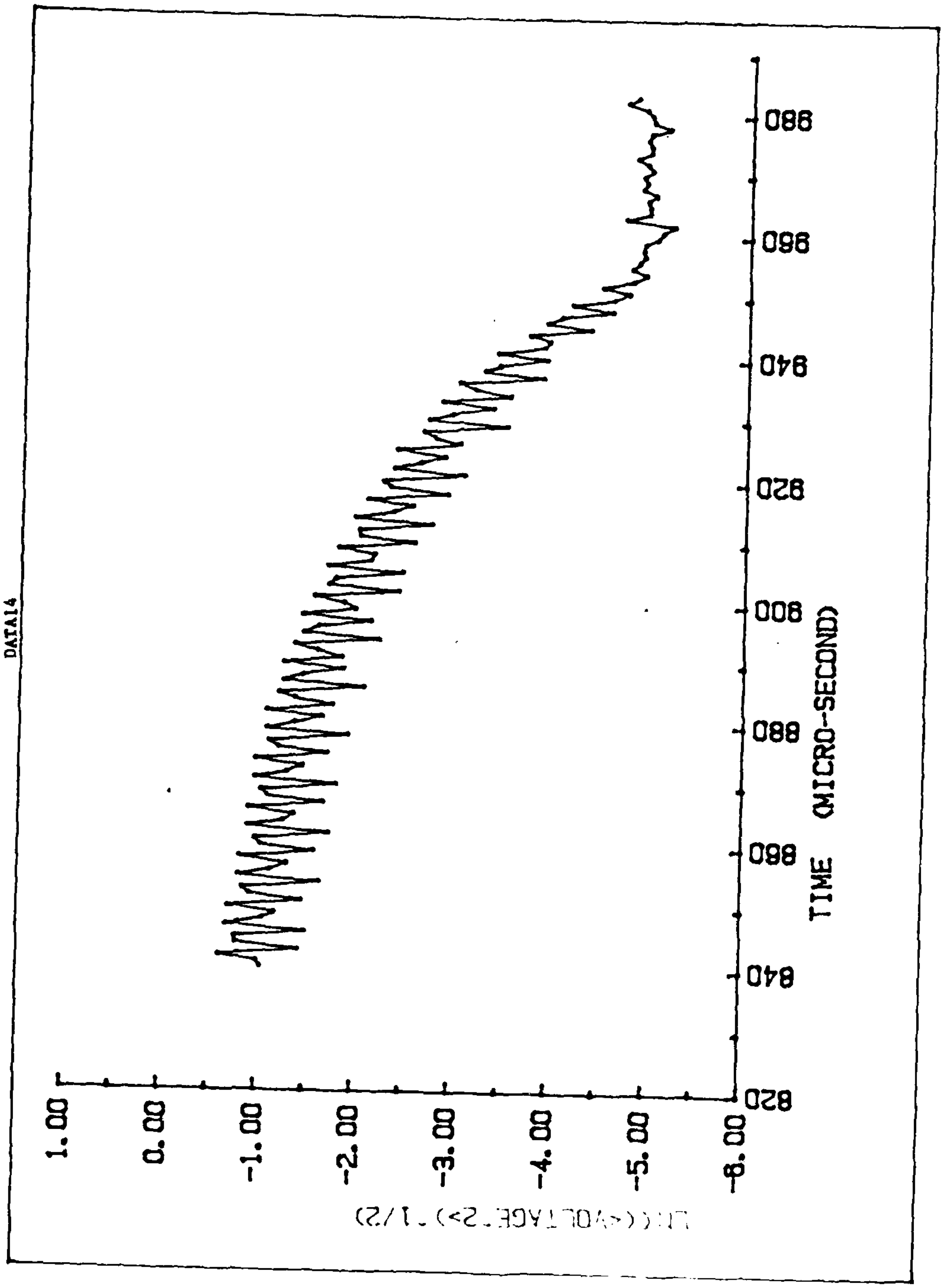
DATA14

LOCAL MAXIMA

	TIME (SEC.)	VOLT
J= 0	.000842	.54045536
J= 1	.000845	.45899455
J= 2	.000847	.50422217
J= 3	.000850	.49352001
J= 4	.000853	.42883796
J= 5	.000855	.44724714
J= 6	.000858	.44041571
J= 7	.000861	.37797354
J= 8	.000863	.40769351
J= 9	.000866	.40645049
J= 10	.000869	.35724781
J= 11	.000871	.38274273
J= 12	.000874	.37784653
J= 13	.000877	.33052988
J= 14	.000879	.34012645
J= 15	.000882	.33712312
J= 16	.000885	.29928248
J= 17	.000887	.28822214
J= 18	.000890	.28938901
J= 19	.000893	.25609764
J= 20	.000895	.23441843
J= 21	.000898	.23726778
J= 22	.000901	.21052791
J= 23	.000903	.18255410
J= 24	.000906	.18451016
J= 25	.000909	.16501515
J= 26	.000912	.13276295
J= 27	.000914	.14031393
J= 28	.000917	.12374975
J= 29	.000920	.10439349
J= 30	.000922	.09439280
J= 31	.000925	.09172786
J= 32	.000928	.06992853
J= 33	.000930	.06643794
J= 34	.000933	.05817216
J= 35	.000936	.04903060
J= 36	.000938	.03776242
J= 37	.000941	.03313608
J= 38	.000944	.02387467
J= 39	.000946	.01994994
J= 40	.000949	.01549193
J= 41	.000952	.01140175
J= 42	.000955	.00836660
J= 43	.000958	.00748331
J= 44	.000963	.00905539
J= 45	.000966	.00721110
J= 46	.000968	.00761577
J= 47	.000970	.00761577
J= 48	.000973	.00812404
J= 49	.000976	.00734847



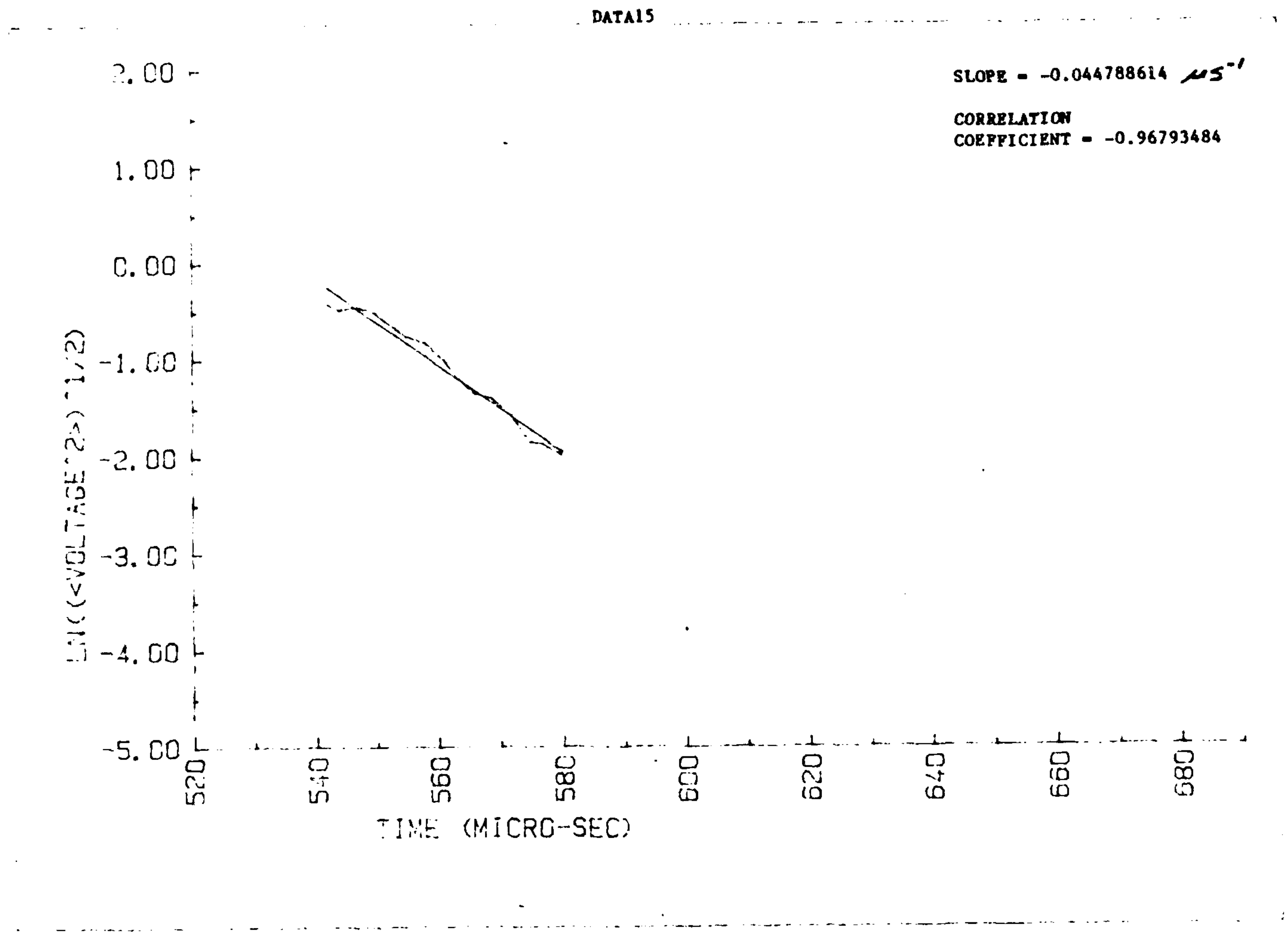
DATA14
SLOPE = -2.535886537 x 10^-2 µs^-1
CORRELATION
COEFFICIENT = -0.83555922
LN((<VOLTAGE^2>)^1/2)
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
820
840
860
880
900
920
940
960
980
TIME (MICRO-SEC)

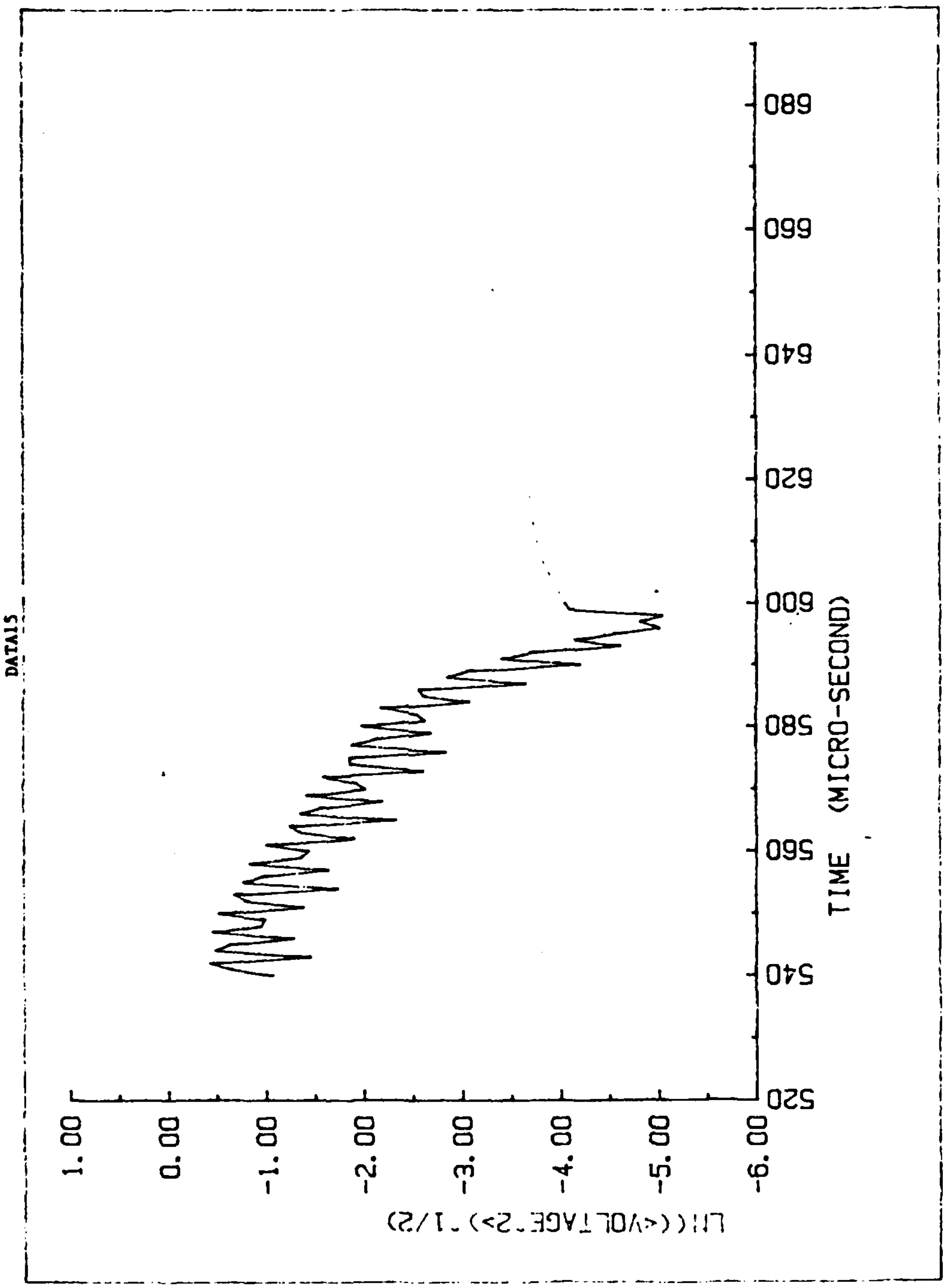

DATA14
TIME (MICRO-SECOND)
820
840
860
880
900
920
940
960
980
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00

DATA15

LOCAL MAXIMA

		TIME (SEC.)	VOLT
J=	0	.000542	.65138314
J=	1	.000544	.61425402
J=	2	.000547	.63677312
J=	3	.000550	.59729390
J=	4	.000553	.51099315
J=	5	.000555	.46395689
J=	6	.000558	.43594954
J=	7	.000561	.36813584
J=	8	.000564	.28952029
J=	9	.000566	.25883199
J=	10	.000569	.24260256
J=	11	.000572	.20407842
J=	12	.000575	.15612815
J=	13	.000577	.15282016
J=	14	.000580	.13717143
J=	15	.000583	.11277411
J=	16	.000586	.07749839
J=	17	.000588	.05820653
J=	18	.000591	.03358571
J=	19	.000594	.01581139

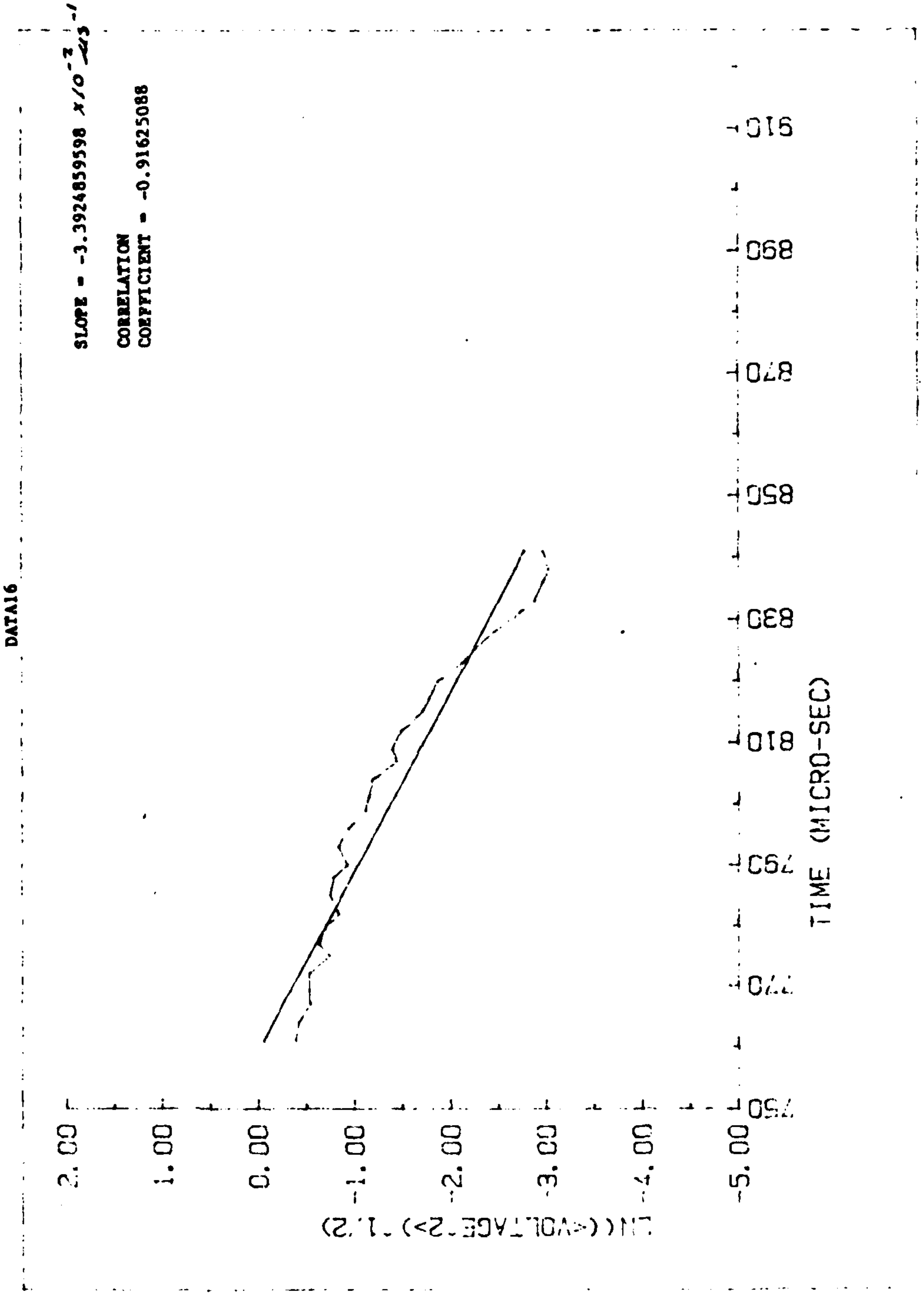

DATA15
SLOPE = -0.044788614 μs⁻¹
CORRELATION
COEFFICIENT = -0.96793484
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
LN((<VOLTAGE^2>)^1/2)
520
540
560
580
600
620
640
660
680
TIME (MICRO-SEC)


DATA15
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
-6.00
520
540
560
580
600
620
640
660
680
TIME (MICRO-SECOND)

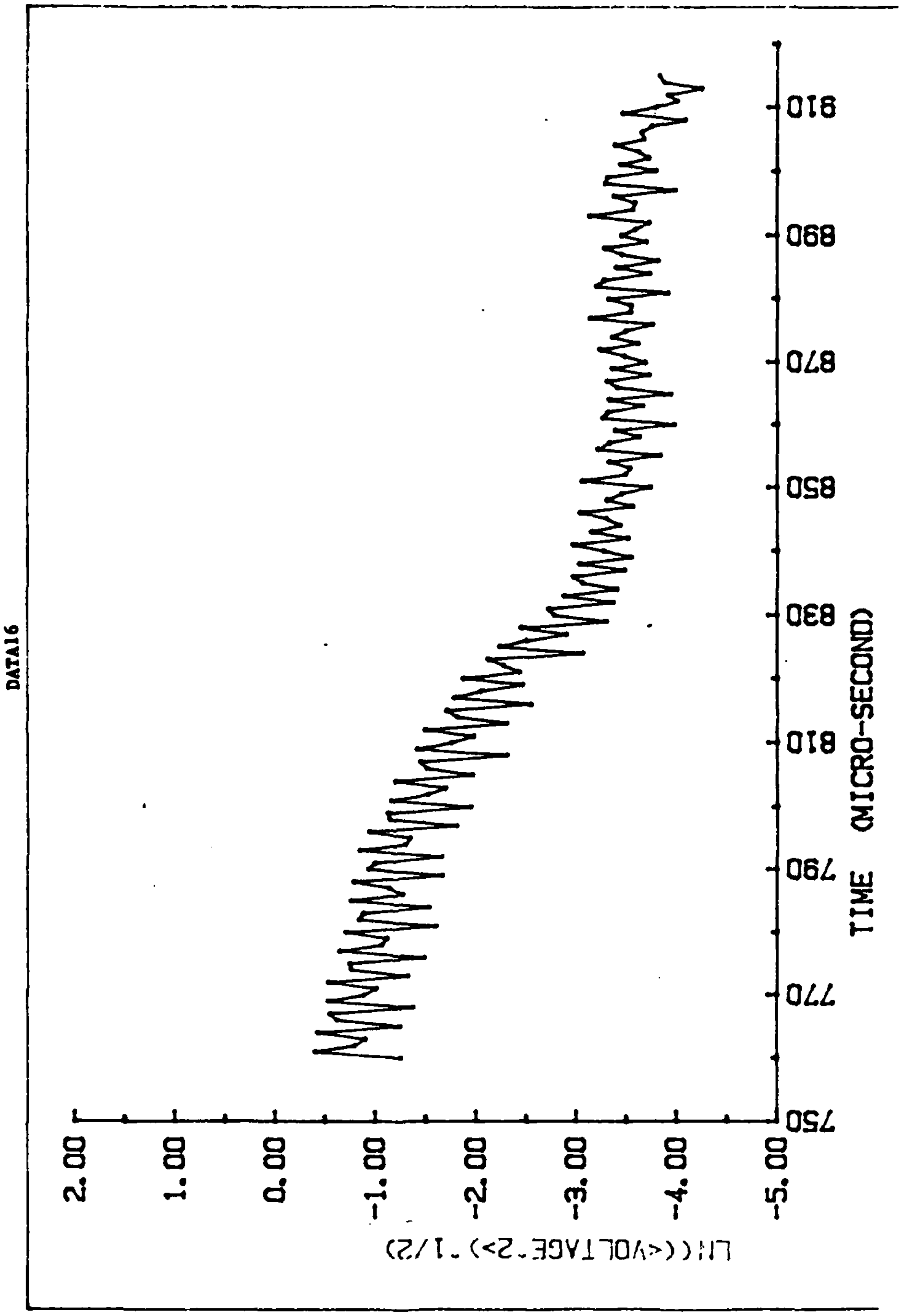
DATA16

LOCAL MAXIMA

	TIME (SEC.)	VOLT
J= 0	.000761	.67368242
J= 1	.000764	.65251513
J= 2	.000767	.57663160
J= 3	.000769	.58674015
J= 4	.000772	.58829924
J= 5	.000775	.47568897
J= 6	.000777	.52818179
J= 7	.000780	.49106415
J= 8	.000782	.43248121
J= 9	.000785	.46876007
J= 10	.000788	.45445352
J= 11	.000790	.39325310
J= 12	.000793	.43202778
J= 13	.000796	.39054833
J= 14	.000799	.32404938
J= 15	.000801	.31501111
J= 16	.000804	.30213904
J= 17	.000807	.23520204
J= 18	.000809	.24467121
J= 19	.000812	.22517549
J= 20	.000815	.18150482
J= 21	.000817	.16956415
J= 22	.000820	.15437616
J= 23	.000823	.12000000
J= 24	.000825	.10703271
J= 25	.000828	.08597674
J= 26	.000831	.06572671
J= 27	.000833	.05635601
J= 28	.000836	.05145872
J= 29	.000838	.04833218
J= 30	.000841	.05130302
J= 31	.000843	.04289522
J= 32	.000846	.04783304
J= 33	.000848	.03676955
J= 34	.000851	.04698936
J= 35	.000854	.03588872
J= 36	.000856	.04039802
J= 37	.000859	.03394113
J= 38	.000861	.03847077
J= 39	.000864	.03600000
J= 40	.000867	.03655133
J= 41	.000869	.03487119
J= 42	.000872	.03939543
J= 43	.000874	.03475629
J= 44	.000877	.04354308
J= 45	.000880	.03622154
J= 46	.000882	.04089010
J= 47	.000885	.03358571
J= 48	.000888	.03762978
J= 49	.000890	.03174902
J= 50	.000893	.04363485
J= 51	.000896	.03417601
J= 52	.000898	.03762978
J= 53	.000901	.03212476
J= 54	.000904	.03405877
J= 55	.000906	.02592296
J= 56	.000909	.03149603



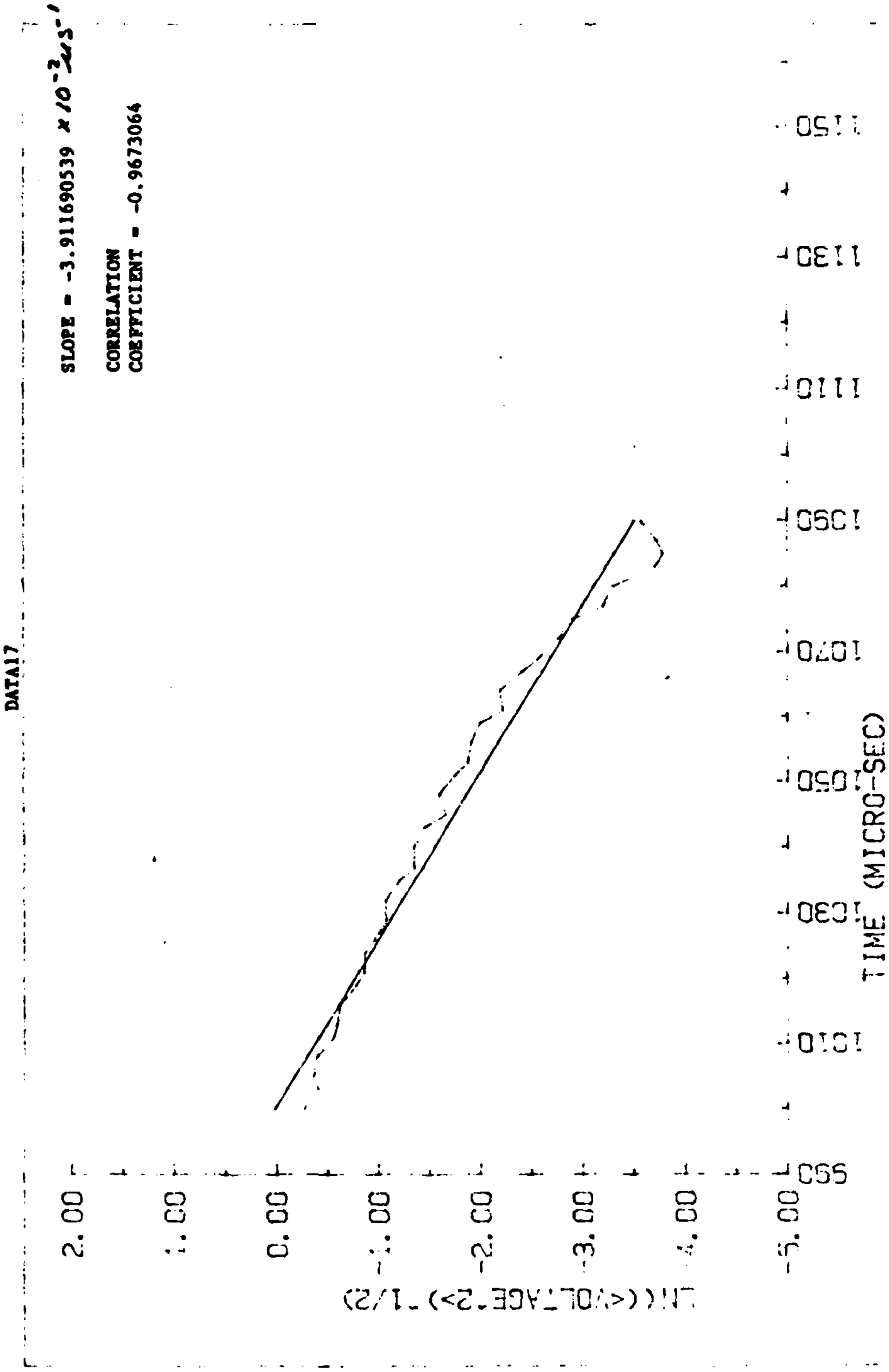
DATA16
SLOPE = -3.3924859598 x10^-2 µs^-1
CORRELATION
COEFFICIENT = -0.91625088
TIME (MICRO-SEC)
750
770
790
810
830
850
870
890
910
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00

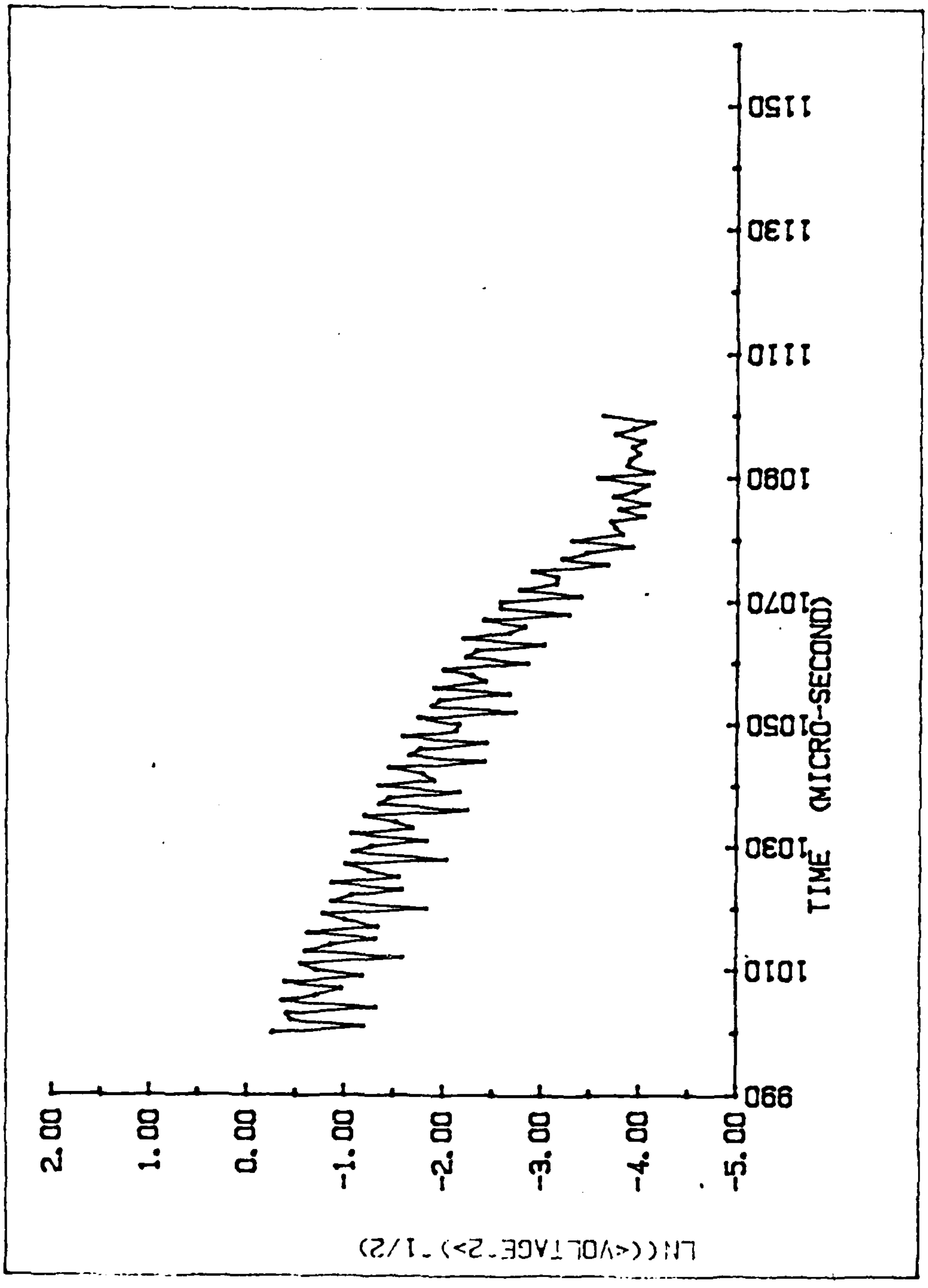

DATA16
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
LN((<VOLTAGE^2>)^1/2)
750
770
790
810
830
850
870
890
810
TIME (MICRO-SECOND)

DATA17

LOCAL MAXIMA

		TIME (SEC.)	VOLT
J=	1	.001003	.66241377
J=	2	.001005	..69465963
J=	3	.001008	.67388426
J=	4	.001011	.57271983
J=	5	.001013	.55145625
J=	6	.001016	.53675320
J=	7	.001019	.45745382
J=	8	.001021	.42155901
J=	9	.001024	.42019995
J=	10	.001027	.36488902
J=	11	.001029	.33958799
J=	12	.001032	.34191227
J=	13	.001035	.29906521
J=	14	.001037	.25879722
J=	15	.001040	.26047649
J=	16	.001043	.23394016
J=	17	.001045	.19047310
J=	18	.001048	.20325354
J=	19	.001051	.17385051
J=	20	.001053	.15252541
J=	21	.001056	.14775656
J=	22	.001059	.13538094
J=	23	.001061	.10829589
J=	24	.001064	.11131936
J=	25	.001067	.09006664
J=	26	.001069	.07668116
J=	27	.001072	.06273755
J=	28	.001075	.05491812
J=	29	.001077	.04049691
J=	30	.001080	.03676955
J=	31	.001083	.02449490
J=	32	.001085	.02262742
J=	33	.001087	.02400000
J=	34	.001090	.02800000
J=	35	.001092	.02078461
J=	36	.001095	.01959592
J=	37	.001097	.02349468


DATA17
SLOPE = -3.911690539 x 10^-2 μs^-1
CORRELATION
COEFFICIENT = -0.9673064
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
LN((<VOLTAGE↑2>)↑1/2)
990
1010
1030
1050
1070
1090
1110
1130
1150
TIME (MICRO-SEC)


DATA17
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00
LN((<VOLTAGE^2>)^1/2)
990
1010
1030
1050
1070
1080
1110
1130
1150
TIME (MICRO-SECOND)

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